U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-106107

Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options Volume XVIII. Particulates Summary Report

Arthur D. Little, Inc., Cambridge, MA

Prepared for

Industrial Research Lab.-Cincinnati, OH

Aug 79

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-79-145
August 1979

Research and Development

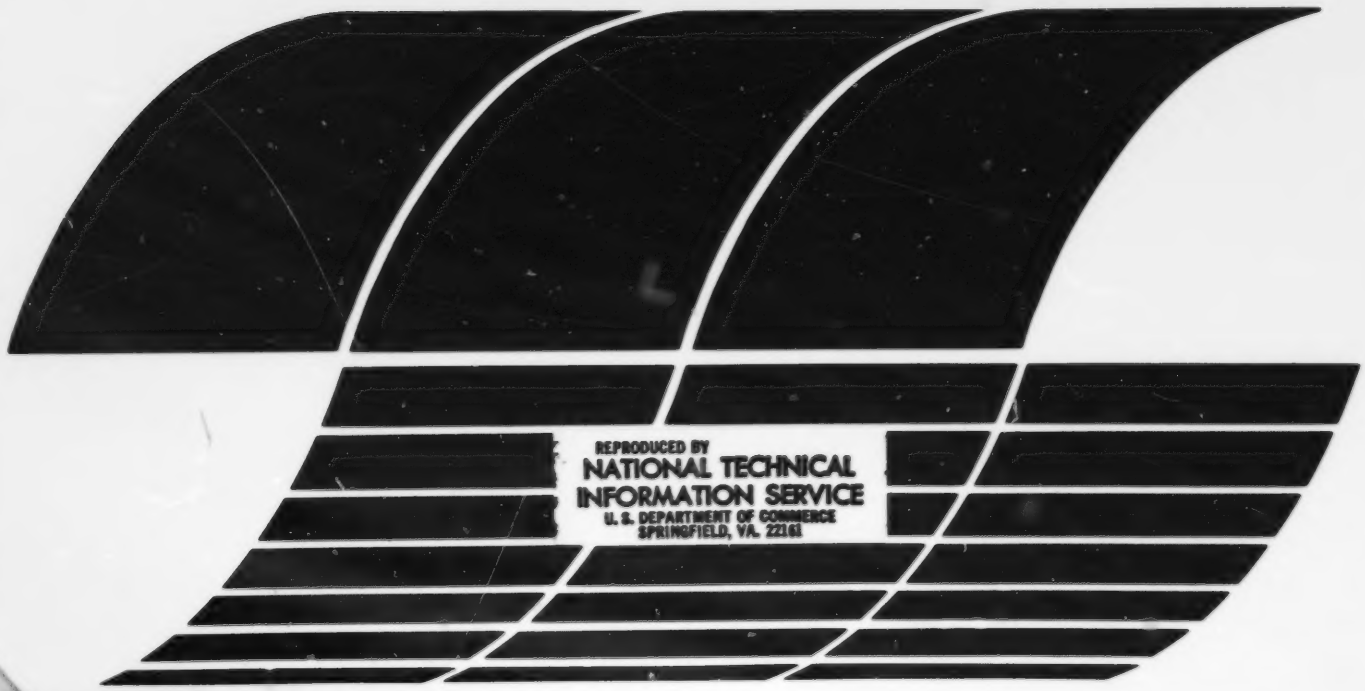
PB80-106107

EPA

Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options

Volume XVIII. Particulates Summary Report

Interagency Energy/Environment R&D Program Report



RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U S Environmental Protection Agency, have been grouped into nine series These nine broad categories were established to facilitate further development and application of environmental technology Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-79-145		

4. TITLE AND SUBTITLE	5. REPORT DATE
Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options - Volume XVIII Particulates Summary Report	August 1979 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Arthur D. Little, Inc.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Arthur D. Little, Inc. 20 Acorn Park Cambridge, MA 02140	1NE 624B
	11. CONTRACT/GRANT NO.
	68-03-2198
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Industrial Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Final
	14. SPONSORING AGENCY CODE
	EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Under EPA Contract No. 68-03-2198, Arthur D. Little, Inc. undertook a study of the "Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options." Some 80 industrial process options were examined in 13 industrial sectors. Results were published in 15 volumes, including a summary, industry prioritization report, and 13 industry oriented reports (EPA-600/7-76-034 a through o).

This present report summarizes the information regarding particulates in the 13 industry reports. Four parallel reports treat sulfur oxides, nitrogen oxides, solid residues and toxics/organics. All of these pollutant oriented reports are intended to be closely used with the original 15 reports.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy, Pollution, Industrial Wastes	Manufacturing Processes, Energy Conservation	68D

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	111
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	PCA06-A01

EPA Form 2220-1 (9-73)

* U.S. GOVERNMENT PRINTING OFFICE 1979 -657-060/5406

EPA-600/7-79-145
August 1979

ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY-CONSERVING MANUFACTURING PROCESS OPTIONS

Volume XVIII. Particulates Summary Report

by

Arthur D. Little, Inc.
Cambridge, Massachusetts 02140

Contract No. 68-03-2198

Project Officer

Herbert S. Skovronek
Power Technology and Conservation Branch
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment, and even on our health, often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report summarizes information on particulates from a study of 13 energy-intensive industries. If implemented over the coming 10 to 15 years, these processes and practices could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives.

The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary.

Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction.

The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Under EPA Contract No. 68-03-2198, Arthur D. Little, Inc. undertook a study of the "Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options." Some 80 industrial process options were examined in 13 industrial sectors. Results were published in 15 volumes, including a summary, industry prioritization report, and 13 industry oriented reports (EPA-600/7-76-034 a through o).

This present report summarizes the information regarding nitrogen oxide pollutants in the 13 industry reports. Four parallel reports treat sulfur oxides, particulates, solid residues, and toxics/organics. All of these pollutant oriented reports are intended to be closely used with the original 15 reports.

CONTENTS

Foreword		iii
Abstract		iv
Tables		vi
English-Metric (SI) Conversion Factors		viii
1.	INTRODUCTION	1
	BACKGROUND AND PURPOSE	1
	APPROACH	2
2.	FINDINGS AND R&D OVERVIEW	5
	FINDINGS	5
	R&D AREAS	15
3.	PROCESS AND POTENTIAL PARTICULATE EMISSIONS	23
	BASES OF CALCULATIONS	23
	PARTICULATE CONTROL METHODS	24
	IRON AND STEEL INDUSTRY	26
	PETROLEUM REFINING INDUSTRY	33
	PULP AND PAPER INDUSTRY	37
	OLEFIN INDUSTRY	44
	ALUMINA AND ALUMINUM INDUSTRY	51
	CEMENT INDUSTRY	59
	GLASS INDUSTRY	63
	PHOSPHORUS/PHOSPHORIC ACID INDUSTRY	70
	COPPER INDUSTRY	77
	AMMONIA INDUSTRY	84
	CHLOR-ALKALI INDUSTRY	87
	FERTILIZER INDUSTRY	91
	TEXTILE INDUSTRY	96
REFERENCES		100
TECHNICAL REPORT DATA (includes abstract)		101

TABLES

Number		Page
1	Projected U.S. Production in Industries Studied	4
2	Summary of Estimated Annual Particulate Emissions	6
3	Nationwide Emissions Estimates for Particulates (1974)	17
4	Estimated Increase in Controlled Particulate Emissions 1989-1974 Assuming Industry Expands Using Process Types Indicated	18
5	Estimated Range in Controlled Particulate Emissions in 1989 for New Processes Likely to be Implemented	21
6	Estimated Particulate Emission Factors - Iron and Steel Industry	27
7	Estimated Particulate Emissions - Iron and Steel Industry	28
8	Estimated Particulate Emission Factors - Petroleum Refining Industry	38
9	Estimated Particulate Emissions - Petroleum Refining Industry	39
10	Estimated Particulate Emission Factors - Pulp and Paper Industry	43
11	Estimated Particulate Emissions - Pulp and Paper Industry	45
12	Estimated Particulate Emission Factors - Olefin Industry	49
13	Controlled Estimated Particulate Emissions - Olefin Industry	50
14	Estimated Controlled Particulate Emission Factors - Alumina and Aluminum Industry	56
15	Estimated Particulate Emissions - Alumina and Aluminum Industry	57
16	Estimated Particulate Emission Factors - Cement Industry	64
17	Estimated Particulate Emissions - Cement Industry	65
18	Estimated Particulate Emission Factors - Glass Industry	67
19	Estimated Controlled Particulate Emissions - Glass Industry	71

TABLES (cont.)

Number		Page
20	Estimated Particulate Emission Factors - Phosphoric Acid Industry	75
21	Estimated Particulate Emissions - Phosphoric Acid Industry	76
22	Estimated Particulate Emission Factors - Primary Copper Industry	82
23	Estimated Particulate Emissions - Copper Smelting	83
24	Estimated Controlled Particulate Emissions - Ammonia Industry	85
25	Estimated Particulate Emissions - Chlor-Alkali Industry	90
26	Estimated Controlled Particulate Emissions - Fertilizer Industry	94
27	Estimated Particulate Emissions - Textile Industry	99

LIST OF FIGURES

1	Particulate Control Device Performance Comparison	25

ENGLISH-METRIC (SI) CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	$Metre^2$	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	$Metre^3$	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t_C^o = (t_F^o - 32)/1.8$
Degree Rankine	Degree Kelvin	$t_K^o = t_R^o/1.8$
Foot	Metre	0.3048
$Foot^3$/minute	$Metre^3$/sec	0.0004719
$Foot^3$	$Metre^3$	0.02831
$Foot^2$	$Metre^2$	0.09290
Foot/sec	Metre/sec	0.3048
$Foot^2$/hr	$Metre^2$/sec	0.00002580
Gallon (U.S. liquid)	$Metre^3$	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	$Metre^3$	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (Assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANS72101-1973) (ASTM Designation E380-72)

SECTION I

INTRODUCTION

BACKGROUND AND PURPOSE

During 1975 and the first half of 1976, under EPA Contract No. 68-03-2198, Arthur D. Little, Inc., undertook a study of the "Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options" in 13 energy-intensive industry sectors for the U.S. Environmental Protection Agency (EPA). The results of these studies were published in the following reports:

- Volume I -- Industry Summary Report (EPA-600/7-76-034a)
- Volume II -- Industry Priority Report (EPA-600/7-76-034b)
- Volume III -- Iron and Steel Industry Report (EPA-600/7-76-034c)
- Volume IV -- Petroleum Refining Industry Report (EPA-600/7-76-034d)
- Volume V -- Pulp and Paper Industry Report (EPA-600/7-76-034e)
- Volume VI -- Olefins Industry Report (EPA-600/7-76-034f)
- Volume VII -- Ammonia Industry Report (EPA-600/7-76-034g)
- Volume VIII -- Alumina/Aluminum Industry Report (EPA-600/7-76-034h)
- Volume IX -- Textile Industry Report (EPA-600/7-76-034i)
- Volume X -- Cement Industry Report (EPA-600/7-76-034j)
- Volume XI -- Glass Industry Report (EPA-600/7-76-034k)
- Volume XII -- Chlor-Alkali Industry Report (EPA-600/7-76-034l)
- Volume XIII -- Phosphorus/Phosphoric Acid Industry Report (EPA-600/7-76-034m)
- Volume XIV -- Copper Industry Report (EPA-600/7-76-034n)
- Volume XV -- Fertilizer Industry Report (EPA-600/7-76-034o)

In the course of this study, we examined some 80 industrial process options focussing on:

- Identification of any major sources of pollutants (air, water, and solid residues) expected from the processes,

- Development of estimated capital and operating costs for both production and pollution control aspects of the processes,
- Estimation of the types and amounts of energy used in both production and pollution control for the processes,
- Assessment of the economic viability and likelihood of implementation of those alternative process options being studied,
- Identification of areas where EPA's activities and policies could influence the future choice of alternatives, and
- Identification of research and development areas in both process and pollution control technology.

Because of the industry orientation of the sutdy, the 15 volumes of which consisted of 1,700 pages, we felt we needed to summarize pollutant-specific information across all the 13 sectors studied. Five such pollutants were identified to be of particular interest:

- Nitrogen oxide (NO_x) emissions,
- Sulfur oxide (SO_x) emissions,
- Fine particulate emissions,
- Solid residues, and
- Organic and/or toxic pollutants.

A summary pollutant report in each of these areas has been prepared. Although some estimates and extrapolations on pollutants have been attempted where the information was readily available, in general, we have not attempted to go beyond the 15 original reports.

APPROACH

These summary pollutant reports are intended to be used closely with the original 15 reports. Generally, information, such as detailed descriptions of the processes, has not been duplicated in these pollutant reports. Sections of the previous 15 reports where this information can be found have been extensively referenced by volume number and page number (e.g., Vol. VII, page 20, refers to page 20 of the Ammonia Industry Report).

In Section 2 of this report (Findings and R&D Overview), summary information on generic, cross-industry problems that emerged and suggestions for R&D work in the areas of both pollution control technology and process technology are presented. In Section 3 of this report, the

availability and applicability of particulate pollution control technology are presented, and fine particulate emissions and controls reported in our previous study are reviewed. All emissions are estimated, unless specifically referenced, since we believe that actual data do not exist for many of the processes described.

To give the reader a sense of the size of the industries for which the pollution problems covered in these summary pollutant reports are considered, Table 1 lists these industries, their total production in 1974 (the base case year for the study), and their projected incremental production in 1989, 15 years hence. This information can be used to calculate readily a gross estimate of the pollutant load (e.g., particulates) which can be expected in 1989, assuming that the specific process accounts for all incremental production in that year relative to 1974. Similarly, expected total emissions can also be determined.

TABLE 1. PROJECTED U.S. PRODUCTION IN INDUSTRIES STUDIED

Commodity	Total U.S. projection in 1974 (10^6 tons*)	Projected rate of growth (%/yr)	Total projected production in 1989 (10^6 tons)	Increase in annual production in 1989 over that of 1974 (10^6 tons)
Alumina	7.7	6.0	18.5	10.8
Aluminum	5.0	6.0	12.0	7.8
Ammonia	9.2	6.0	22.0	12.8
Cement	79.0	2.0	106.3	27.3
Chlorine	11.0	5.0	22.9	11.9
Coke	62.0	2.5	89.8	27.8
Copper	1.6	3.5	2.7	1.1
Fertilizers (HNO_3)	8.2	4.0	14.8	6.6
Glass (flat)	29.0	2.5	42.0	13.0
Iron	100.0	2.5	144.8	44.8
Olefins (ethylene)	13.0	8.0	41.2	28.2
Petroleum	740.0**	1.5	925.0***	185.0****
Pulp (Kraft)	16.0	5.0	33.0	17.3
Pulp (newsprint)	3.9	2.5	5.6	1.7
Phosphoric Acid (detergent grade)	1.4	2.5	2.03	0.63
Phosphoric Acid (wet acid grade)	9.0	2.5	13.0	4.0
Steel	133.0	2.5	193.0	60.0
Textiles (knit)	0.32	2.2	0.44	0.12
Textiles (woven)	2.1	2.2	2.91	0.81

*All tons referred to in these reports are net tons, unless otherwise indicated.
**Approximate equivalent of 30 quads (1 quad is equal to 10^{15} Btu).
***Approximate equivalent of 37.5 quads.
****Approximate equivalent of 7.5 quads.

SECTION 2

FINDINGS AND R&D OVERVIEW

FINDINGS

The thirteen industries addressed in the original study have particulate pollution problems which are affected by the process changes and, therefore, are covered in this report. Table 2 summarizes the estimated particulate emissions from both the base case processes and process alternatives for these industries.

The emission factors shown in the table include both process and power boiler emissions. These factors do not include fugitive* (area) emissions, but are limited to source emissions. Emissions from the power boiler were generally not considered in the original study; however, they have been included here to make comparisons of emissions from the baseline and alternative processes more comprehensive. Both on-site power boilers for steam and electricity generation and off-site utility power boilers for electricity generation are considered. The total particulate emission factors for processes with pollution control vary from about 0.2 lb/ton to 100 lb/ton of product.

In some processes, such as production of aluminum in electrolytic cells using the Hall-Heroult process, it may not be possible to completely enclose the emission source. In such cases, emissions escaping the collection device are significant and generally exceed controlled emissions. Therefore, the emission factor for the Hall-Heroult process of the aluminum industry is high.

Estimated particulate emissions based on best available control technology for 1974 from the processes studied are shown in Table 2. These controlled emissions are based on estimated emission factors and the 1974 production shown in Table 1. The emission factors are estimated (see Section 3) based on engineering judgments unless referenced. The emissions in Table 2 are from processes studied and therefore do not represent total industry emissions. Industries responsible for the largest quantities of particulate emissions are steel, aluminum, and petroleum refining. Industries having more moderate emissions include pulp and paper, alumina, and cement.

---

*Fugitive emissions are defined as area emissions. Emissions escaping the hoods are not included in fugitive emissions as these are source emissions and not area emissions.

TABLE 2. SUMMARY OF ESTIMATED ANNUAL PARTICULATE EMISSIONS

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions[a] (1989-1974) (10^6 lb/yr)	Change in particulate emissions from base case[b] (in 1989) (10^6 lb/yr)
Petroleum	Base case: East Coast refinery	339.0[c]	84.8[c]	--
	• Direct combustion of asphalt in process heaters and boilers	--	114.8[c]	+ 30[c]
	• Flexicoking	--	85.5[c]	+ .7[c]
	Base case: Gulf Coast refinery	354.0[c]	88.5[c]	--
	• On-site electric power by combustion of vacuum bottoms	--	88.5[c]	0
	Base case: West Coast refinery	420.0[c]	105.0[c]	--
	• Hydrocracking of heavy bottoms	--	112.5[c]	+ 7.5[c]
	• High-purity hydrogen via partial oxidation of asphalt	--	105.0[c]	--

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974)[a] (10^6 lb/yr)	Change in particulate emissions from base case (in 1989)[b] (10^6 lb/yr)
Alumina	Base case: Bayer process	59.3	83.2	--
	• Hydrochloric acid ion exchange	--	47.5	- 35.7
	• Nitric acid ion exchange	--	N.A.	N.A.
	• Toth alumina	--	N.A.	N.A.
Aluminum	Base case: Hall-Heroult (current practice, C.P.)	242-487	338.4-681.8	--
	• Hall-Heroult (new)	--	130.2	-208.2 to -551.6
	• Alcoa chloride	--	N.A.	N.A.
	• Refractory hard metal cathode	--	315.7-660.8	- 22.7 to -21.0
	Base case: Bayer with Hall-Heroult (C.P.)	356-601	499-842	--

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974)[a] (10^6 lb/yr)	Change in particulate emissions from base case (in 1989)[b] (10^6 lb/yr)
Aluminum (cont)	• Clay chlorination (toth alumina) and aloca chloride	--	N.A.	N.A.
Kraft pulp	Base case: Kraft pulping	57.6	62.3	--
	• Alkaline oxygen pulping	--	62.3	0
	• Rapson effluent-free Kraft pulping	--	59.0	- 3.3
Newsprint pulp	Base case: Refiner mechanical pulp (RMP)	7.8	3.4	--
	• Thermo-mechanical pulp (TMP)	--	2.4	- 1.0
	• De-inking of old news for newsprint manufacture	--	1.0	- 2.4

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974)[a] (10^6 lb/yr)	Change in particulate emissions from base case (in 1989)[b] (10^6 lb/yr)
Flat glass	Base case: Regenerative furnace	3.5	1.6	--
	• Coal gasification	--	∿ 1.6	∿ 0
	• Direct coal firing	--	> 1.6	N.A.
	• Coal-fired hot gas generation	--	N.A.	N.A.
	• Electric melting	--	∿10.7	+ ∿ 9.1
	• Batch preheat with natural gas firing	--	∿ 1.6	∿ 0
Copper	Base case: Conventional smelting	1.3	.9	--
	• Outokumpu flash smelting	--	3.8	+ 2.9
	• Noranda	--	.9	0
	• Mitsubishi	--	.9	0
	• Arbiter	--	5.7	+ 4.8

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974)[a] (10^6 lb/yr)	Change in particulate emissions from base case[b] (in 1989) (10^6 lb/yr)
Chlorine, NaOH	Base case: Graphite-anode diaphragm cell	39.6	42.8	--
	• Dimensionally stable anodes	--	41.1	- 1.7
	• Expandable DSA	--	37.0	- 5.8
	• Polymer modified asbestor	--	37.6	- 5.2
	• Polymer membrane	--	37.6	- 5.2
	• Ion exchange membrane	--	37.6	- 5.2
	• Mercury cell	--	46.5	+ 3.7
Steel	Base case: No off-gas recovery	69.2	31.2	--
	• Off-gas recovery	--	15.6	-15.6
Blast furnace hot metal	Base case: Blast furnace	150.0	67.5	--
	• Blast furnace with external desulfurization	--	81.0	+13.5

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions[a] (1989-1974) (10^6 lb/yr)	Change in particulate emissions from base case[b] (in 1989) (10^6 lb/yr)
Coke	Base case: Wet quenching of coke	80.6	58.5	--
	• Dry quenching of coke	--	54.0[d]	- 4.5[d]
Steel (integrated)	Base case: Steelmaking: coke oven, blast furnace BOP route	452.2	204.0	--
	• Direct reduction, EAF route	--	66.0	-138
Phosphoric acid (detergent grade)	Base case: Electric furnace	15.3	6.9	--
	• Chemical cleanup of wet-process acid	--	1.7	- 5.2
	• Solvent extraction of wet-process acid	--	5.4	- 1.5

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974)[a] (10^6 lb/yr)	Change in particulate emissions from base case (in 1989)[b] (10^6 lb/yr)
Fertilizers (nitric acid)	Base case: No NO_x control	- .08	- .07	--
	• Catalytic reduction	--	- .07	0
	• Molecular sieve	--	2.9	+ 2.97
	• Grand Paroisse	--	.07	+ .14
	• CDL/Vitak	--	7.7	+ 7.77
	• Masar	--	13.9	13.97
Fertilizers (mixed): converting fertilizer dryers (with baghouses) from natural gas to oil				
	Base case: Natural gas	.11	< 0.08	--
	• Better equipment technique with fuel oil	--	< 0.08	0
	• Installing scrubbers	--	< 0.16	+ .08

(continued)

TABLE 2. (continued)

Commodity	Process	Controlled particulate emissions in 1974 from base case process (10^6 lb/yr)	Controlled particulate emissions (1989-1974) (10^6 lb/yr)	Change in particulate emissions from base case (in 1989) (10^6 lb/yr)
Textiles	Knit fabric:			
	• Base case: Conventional aqueous	.17	0.06	--
	• Advanced aqueous	--	0.07	+ .01
	• Solvent processing	--	0.03	- .03
	Woven fabric:			
	• Base case	2.5	0.98	--
	• Advanced aqueous	--	0.46	- .52

[a]Based on incremental production from the year 1974 to 1989 derived from anticipated growth rates (Table 1).

[b]Assumes no retirement of existing facilities by 1989.

[c]National emission rates calculated as though the alternative process applies to all national oil refinery production.

[d]Change estimated from base case.

N.A. - not available.

$\sim$ approximately equal to

The data in Table 2 represent mass data. The data are significantly affected by changes in the emissions of large particulates because large particulates contribute more to the mass than do small particulates. Though such large particulates can be effectively controlled, in some cases they do escape from the collection device. On the other hand, although fine particulates contribute little to the mass of particulate emissions, they may have a significant effect on health and visibility. The particulate emissions in this report represent total emissions and are not segregated according to the particle size because such information cannot be estimated for new processes now in the development phase. Estimated particulate emissions, based on projected incremental production from 1974 to 1989, are also listed in Table 2. Maximum incremental emissions are shown for both the base case and alternative processes, assuming dedication of 100% of the incremental production rather than a fraction to each process (base case and alternative).

Total real (albeit estimated) emissions from production of each commodity in the year 1989 would be the sum of emissions from the base case and all alternative processes, each in proportion to the fraction of the total 1989 production for which it accounts. Obviously, it is not possible to estimate or extrapolate most of these fractions with any degree of confidence, nor is it necessarily valid to assume that the 1974 base case process would continue to account for the same volume of production as in 1974. In fact, certain newer, energy-conserving processes may be preferred, not only for incremental production but also for replacement production. Of course, it would be equally unrealistic in most cases to predict that new technology, even with energy and environmental advantages, would totally displace existing technology.

The estimated increase or decrease in emissions from each alternative process in relation to its base case process is also shown in Table 2. This change is based on incremental capacity. As the table shows, the greatest potential for emission reduction exists in two industries: (1) iron and steel, with direct reduction of iron ore and coke production using dry quenching, and (2) aluminum, with the use of new prebake cells.

All of the process alternatives studied (Volumes III to XV) are aimed at reduction in energy consumption, or conversion to more plentiful fuel forms. Particulate emission is directly related to boiler fuel consumption so fuel-conserving process changes will reduce particulate emissions from boilers. However, conservation through conversion to more plentiful fuel forms includes the switch from natural gas to either oil or coal, from oil to coal, and then from natural gas to asphalt. Such changes will cause increased emissions because boilers burning oil, coal, or asphalt will inherently generate more particulates and will require particulate control equipment. Even then, their controlled emissions will generally exceed the uncontrolled emissions from boilers burning natural gas.

R&D AREAS

The following R&D areas have been identified as worthy of consideration by industry, government agencies, or other institutions.

Particulate-Related Areas

- Improving fine particulate removal technology should include control of those particulates resulting from metallic smokes and sublimed substances such as mercury, arsenic, and zinc.

- The collection or control of process fugitive emissions is a necessary R&D effort.

- Better quantitative knowledge of the environmental, health, and ecological impacts of metallic smoke emissions is needed to establish appropriate emission regulations.

Process-Related Areas

Iron and Steel--

- Quantitative measurements of fugitive and source emissions from non-combustion BOP gas-collection systems are desirable. Emissions are present during the transition periods at the beginning and the end of a blow, when off-gases are not collected for use as fuel, but their percent contribution and nature are currently unknown.

- A comparison of available equipment for external desulfurization should be made to determine the nature of particulate emissions as a function of the desulfurizing reagent used. Differences in character could contribute to variations in case of removal.

- The quantification and characterization of particulate emissions from rotary kilns (used for direct reduction) are also desirable as a prelude to developing appropriate control technology.

Petroleum Refining--

- Establish particulate emission factors for asphalt combustion. Both uncontrolled and controlled emission factors should be considered and applicable particulate control methods should be defined, evaluated, and cost-analyzed.

Pulp and Paper--

- The de-inking of old newsprint for the manufacture of recycled newsprint presents an opportunity to reduce particulate emissions, as compared to emissions from other processes, because by the very nature of the de-inking process, there are few particulate emissions. Broader commercial application of this process should be supported, because it could also reduce the amounts of municipal solid wastes. However, the impact on "energy from municipal waste" systems should not be ignored.

Aluminum--

- Materials research should be conducted toward producing titanium diboride cathodes capable of long operating life in the Hall-Heroult cell. This development would produce energy savings in the existing aluminum plants, thus reducing particulate emissions at the fossil-fueled electricity-generating plants, and could be a relatively short-term objective.

Cement--

- Develop and implement a commercial-scale test program on a rotary-kiln, cement-making facility equipped with a flash-calciner to characterize particulate emissions. Of particular interest would be the emissions from operating with a bypass of a considerable amount of the combustion gas to eliminate alkalies.

Glass--

- There is presently no proven process for treating emissions from a glass-melting furnace economically. The particulates present a difficult control problem. Research is needed in this area in the immediate time frame for the current process, and will be at least as necessary for the proposed coal-based processes. The ability of a preheating system using waste off-gases to "filter" fine particulates must also be established.

Should U.S. industry expand using current (base case) technology, Table 4 shows that estimated controlled particulate emissions in 1989 would increase by 0.86 to 1.2 x 10^9 lb compared to particulate emissions of 21.2 x 10^9 lb from industrial processes and 68 x 10^9 lb from electric utilities in 1974 (Table 3). However, if all U.S. industry expanded by implementing the technologies considered here that emitted the largest amounts of particulates, Table 4 shows that the increase in particulate

TABLE 3. NATIONWIDE EMISSIONS ESTIMATES FOR PARTICULATES (1974)

Source Category	10^6 lb/yr	% of Total
Transportation	2,600	6.4
Stationary Fuel Combustion		
Electric Utilities	6,800	16.8
Other	7,200	17.7
Industrial Processes	21,200	52.2
Solid Waste	1,200	3.0
Miscellaneous	1,600	3.9
Total	40,000	100.0

Source: National Air Quality and Emissions Trends Report, EPA, Research Triangle Park, N.C., NTIS PB 263-922, 1978.

TABLE 4. ESTIMATED INCREASE IN CONTROLLED PARTICULATE EMISSIONS 1989-1974 ASSUMING INDUSTRY EXPANDS USING PROCESS TYPES INDICATED (10^6 LB PARTICULATE/YR)

Commodity (vol no)*	Base case process	Using process with largest potential particulate emissions	Using process with smallest potential particulate emissions
Steel (III)	204	204	66
Petroleum (IV)	85[a]	115[a]	85[a]
Kraft pulp (V)	62	62	59
Newsprint Pulp (V)	3	3	1
Olefins (VI)	14	23	14
Ammonia (VII)	3	9	2
Alumina (VIII)	83	83	48
Aluminum (VIII)	338-682	338-682	130
Textiles-knit (IX)	.06	.07	.03
Textiles-woven (IX)	1	1	.50
Cement (X)	18	18	13
Flat Glass (XI)	2	11	2
Chlorine, NaOH (XII)	43	47	37
Phosphoric Acid (XIII)	7	7	2
Copper (XIV)	1	6	1
Fertilizers (HNO_3) (XV)	- .1[b]	14	- .1[b]
Total	864-1208	941-1285	450

*Volume number of industry report.

[a]Assumes East Coast refinery model applied nationally

[b]Credit for steam reaised: see text on fertilizers in Section 3 of this report.

emissions in 1989 would be .94 to 1.3 x 10^9 lb or some 10% higher than using conventional technology. On the other hand, if industry expanded by implementing the least particulate-emitting technology, particulate emissions in 1989 are calculated to increase by .45 x 10^9 lb or some 47-63% less than by conventional technology. If the national production growth rate projections shown in Table 1 are accurate, then calculated emissions will probably lie somewhere between these extremes, with energy (Btu) saving processes with lower particulate emissions somewhat balancing the switch from natural and fuel oil to coal. Thus, incentives for the implementation of energy conserving technology can have a significant effect on future particulate emissions in the industrial sector.

Examination of the last column in Table 2 shows that greatest reduction compared to the base case processes in lb of particulate emissions per year can be achieved by selective implementation of new processes in:

- aluminum (Hall-Heroult (new); refractory hard metal cathodes)
- steelmaking (direct reduction, EAF route)
- alumina (hydrochloric acid ion exchange)

Process changes in some of the industries shown in Table 2 may be implemented because of feed stock shortages (e.g., manufacture of olefins from low-sulfur naphtha rather than higher sulfur gas oil), and fuel switching (e.g., use of coal in cement making). In other cases, processes may be developed for other reasons, such as development of a domestic alumina industry based on indigenous kaolin clays. Such a process based on using coal to the extent possible, would result in significantly higher particulate emissions than a Bayer plant based on natural gas, as described in the Alumina/Aluminum Industry report. Although the estimated change in emissions listed in Table 2 was based on incremental capacity from 1974 to 1989 only, in some cases an alternative process or a process modification, may replace existing capacity. For example, in the aluminum industry, refractory hard metal cathodes may be installed in existing Hall-Heroult cells. The application of alternative processes to existing plant capacity (i.e., retrofitting) will increase the potential effect on particulate emissions, compared to the estimated effect shown in Table 2. Further perspectives in each of these industry sectors with descriptions of the processes can be obtained from the individual industry sector reports (Volumes III through XV).

To give some perspective to the magnitude of particulate emissions, Table 3 shows the industrial process category to be the largest emitter of particulates.

Table 5 shows our estimate of the types of processes likely to be installed in the time period up to 1989 with the related particulate emissions from new plants calculated for the year 1989 assuming no retirement of existing facilities. For example, a reading of the industry reports shows that in the phosphoric acid manufacture incremental detergent

grade acid capacity will be effected most probably by wet acid cleanup processes. If such capacity is installed, anticipated annual particulate emissions in 1989 would be 2×10^6 lb particulate/year (Table 5) compared to the 7×10^6 lb particulate /year if conventional electric furnace technology were employed. Similar judgments were made in other sectors to arrive at total calculated annual emissions of .6 to .7 $\times 10^9$ lb particulates emitted in 1989 from new plant capacity installed in the period 1974-1989.

TABLE 5. ESTIMATED RANGE IN CONTROLLED PARTICULATE EMISSIONS IN 1989 FOR NEW PROCESSES LIKELY TO BE IMPLEMENTED

Commodity (vol no)*	Likley types of processes to be implemented in new plants	Calculated range in annual particulate emissions for new plant capacity-1989 (10^6 lb/yr)
Steel (III)	Coke oven, blast furnace, BOP[b]	188[c] - 204
Petroleum (IV)	Hydrocracking, flexicoking, etc.	86 - 115[d]
Kraft pulp (V)	Kraft, Rapson, alkaline-oxygen	59 - 62
Newsprint pulp (V)	RMP, TMP, de-inking	1 - 3
Olefins (VI)	Naphtha, gas oil	19 - 23
Ammonia (VII)	Heavy fuel oil, coal	2 - 9
Alumina[a] (VIII)	Bayer, leaching domestic clays	48 - 83
Aluminum[a] (VIII)	Hall-Heroult[a] (aluminum chloride)	130 - 130
Textiles, knit (IX)	Advanced aqueous, solvent	.03 - .07
Textiles, woven (IX)	Advanced aqueous	.50 - .50
Cement (X)	Preheaters, coal firing, etc.	13 - 18
Flat glass (XI)	Regenerative furnaces, preheaters, electric furnaces	2 - 11
Chlor-alkali (XII)	Dimensionally stable anodes, new membranes	38 - 41
Phosphoric acid: detergent grade (XIII)	Wet acid cleanup	2 - 2
Copper (XIV)	Oxygen or flash processes[b]	1 - 4
Fertilizers-nitric acid (XV)	Various NO_x control technologies	-.07 - 14
TOTAL		589 - 720

*Volume number of industry report.

[a]A significant fraction of the incremental U.S. demand is expected to be imported.

[b]In addition, electric furnaces are expected to be installed based at least partially on scrap iron and steel.

(continued)

TABLE 5. (continued)

[c]With collection of CO from BOFs.

[d]Assumes East Coast refinery model applied nationally.

SECTION 3

PROCESS AND POTENTIAL PARTICULATE EMISSIONS

BASES OF CALCULATIONS

In Volume II (p. 19) where the methodology is described, we indicated that selected State air emission regulations, along with the Federal Government's stationary source performance standards and effluent limitation guidelines, were surveyed to:

- establish the most probable limits of air emissions, and
- obtain a perspective of the types of pollution control systems to be considered.

While there are a large number of different regulations for airborne emissions, at the State regulatory level we found that approximately the same type of air pollution control systems would be required, regardless of the State or Federal regulations to be met. Generally these air pollution control systmes included baghouses, venturi scrubbers, inertial collectors, and electrostatic precipitators for particulates and chemical-based systems for sulfur removal, such as alkaline-based aqueous scrubbing for SO_x.

In this section, we summarize specific methods of particulate control of emissions from the process industries (Volumes III to XV). Only point emissions, not area or fugitive emissions, are considered. There are two sources of emissions: the processes themselves and power boilers.* While emissions from power boilers generally were not considered in the original study, they are included in the present analysis to show the net change in emissions resulting from a process change. For this discussion, power boilers are assumed to burn coal containing 12 percent ash and having a heating value of 12,000 Btu/lb. Approximately 80 percent of the ash appears as fly ash in the pulverized coal-fired boilers so the estimated uncontrolled emission factor for boilers is 192 lb of particulate/ton of coal or 8 lb/10^6 Btu (0.084 lb/kWh, based on 10,500 Btu/kWh). This factor is identical to that reported in AP-42 (EPA, 1975). The New Source Performance Standard (NSPS) established by the U.S. Environmental Protection Agency (EPA) limits the emissions from new, pulverized coal-fired boilers with a capacity greater than 250 x 10^6 Btu/hr to 0.1 lb/10^6 Btu (equivalent to 0.00105 lb/kWh). With existing economically viable control technology (electrostatic precipitators, scrubbers, and bagfilters), this level of control has been achieved. The particulate

*Power boilers are used to generate steam and electricity. Both on-site power boilers and off-site utility power boilers are considered and, for the purposes of this study, both are presumed to be coal-fired.

emission factors for the base case and alternative processes were estimated, and then the effect of the estimated factors on the incremental production from 1974 to 1989 was calculated.

Occasionally, a process involves obtaining a credit for by-product energy such as steam. If the steam can be utilized, it will eliminate the need for burning a fuel with its concommitant emissions. We show such cases in this study as resulting in negative emissions.

PARTICULATE CONTROL METHODS

As indicated earlier, there are four types of equipment employed to remove particulates: inertial collectors, bag filters, wet scrubbers, and electrostatic precipitators.

Inertial Collectors

The cyclone is the most widely used inertial collector in industry. Particulates are separated from the gas stream by virtue of centrifugal force acting on the particulates in the cyclones. Cyclones can effectively separate particles over 5 microns in diameter (greater than 90% efficiency).

Bag Filters

Bag filters (or "baghouses", as they are often called) offer high separation efficiency, even for small particle sizes. In most cases, efficiencies range from 95% to more than 99%. Furthermore, bag filters produce dry dust ready for use or disposal, and (unlike wet scrubbers) they do not add a plume to the stack exhaust.

In the operation of a bag filter, dust-laden gas enters a porous medium and deposits dust in the voids. As the voids fill up, the pressure drop increases, and a point is reached when the fabric must be cleaned. The operation is resumed after the cleaning process.

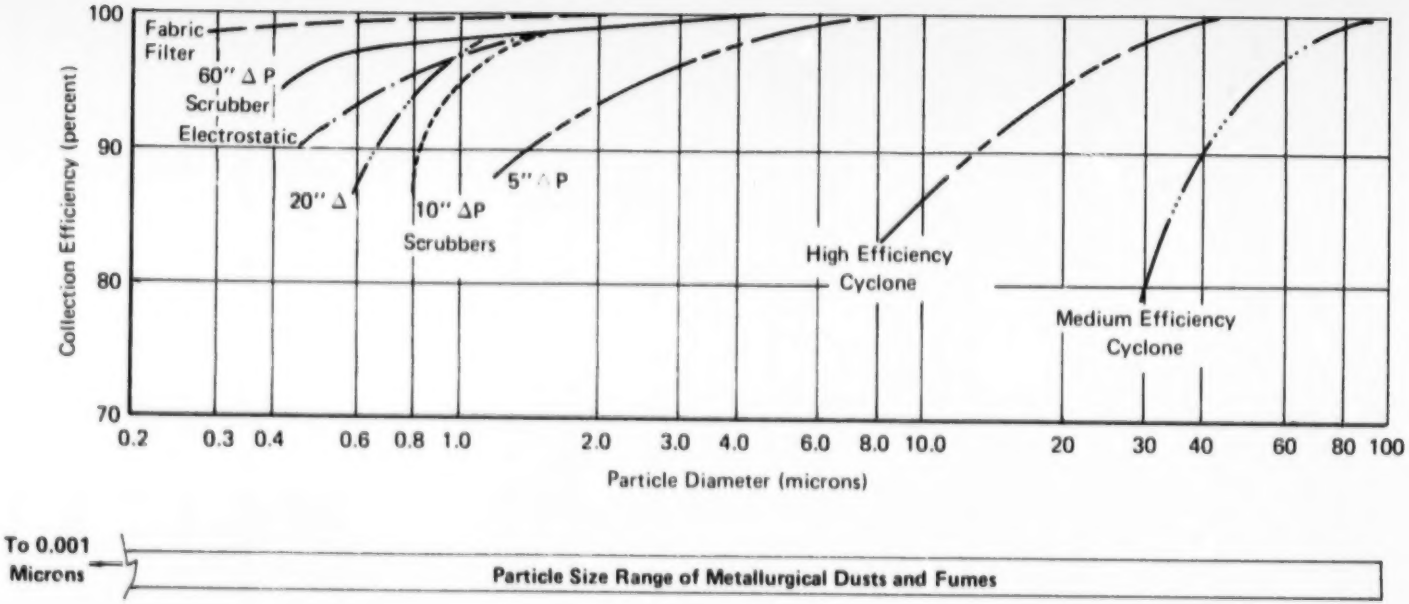
Wet Scrubbers

The major types of wet scrubbers available are: cross flow, countercurrent, wet cyclone, venturi, and vertical air washers.

Wet scrubbers have the following advantages:

- Ability to maintain constant pressure drop (a variable flow rate)
- No secondary dust problem, and
- Ability to handle high-temperature or high-humidity gases.

Scrubbers can handle corrosive gases or aerosols. Usually total space requirements are moderate. But, in some cases, disposal of wastewater is a severe secondary pollution problem.



Source: Arthur D. Little, Inc.

FIGURE 1 PARTICULATE CONTROL DEVICE PERFORMANCE COMPARISON

Electrostatic Precipitators

When suspended particulates in a gas are exposed to gas ions in an electrostatic field, they become charged and migrate to the opposite electrode. Electrostatic precipitators employ this method to separate solid particulates or aerosols from gas streams. Precipitators are made in two basic designs: plate type, mainly used to remove solids from gas streams; and tube type, mainly used to remove aerosols and fumes from gas streams.

Performance of Particulate Control Devices

The comparative performance of particulate control devices is shown in Figure 1. The application range of the various types of equipment is determined by the following factors:

- Particulate characteristics, such as particle size and size distribution, particle shape, particle density, and physico-chemical properties (corrosiveness, hygroscopic tendencies, stickiness, flammability, toxicity, etc.);
- Carrier gas characteristics, such as temperature, pressure, density, viscosity, dew points of condensable components, electrical conductivity, corrosiveness, and flammability;
- Process factors, such as volumetric gas rate, particulate concentration, variability of material flow rates, collection efficiency requirements, and allowable pressure drop; and
- Operational factors, including structural limitations such as head room and floor space, and material limitations such as pressure, temperature, and corrosion service requirements.

IRON AND STEEL INDUSTRY

Summary

In the iron and steel industry, four alternative processes were studied:

- Recovery of carbon monoxide from the basic oxygen process (BOP),
- External desulfurization of blast-furnace hot metal,
- Conversion from wet to dry coke quenching, and
- Direct reduction of iron ore.

Each alternative corresponds to a different base case process. Particulate emissions from the base case and alternative processes are summarized in Tables 6 and 7. Further details on these four process options are discussed next.

TABLE 6. ESTIMATED PARTICULATE EMISSION FACTORS - IRON AND STEEL INDUSTRY

Process	Emission factor - no control (lb/ton of product)			Emission factor - with control (lb/ton of product)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: BOP with no off-gas recovery	55.0	1.2	56.2	0.51	0.01	0.52	99.1
• Off-gas recovery	55.0	0.67	55.7	0.25	0.01	0.26	99.5
Base case: Blast furnace	1.5	2.1	3.6	1.5	0.03	1.5	58.3
• Blast furnace with external desulfurization	7.2	2.1	9.3	1.78	0.03	1.8	80.6
Base case: Wet quenching of coke	2.1	-	2.1	1.3	-	1.3	38.1
• Dry quenching of coke	1.3	- 8.1	- 6.8	1.3	- 0.1	1.2	-
Base case: Steelmaking							
• Coke oven, BF, BOP route	58.0	3.3	61.3	3.4	0.04	3.4	94.4
• Direct reduction route	9.9	58.0	67.9	0.33	0.73	1.1	98.4

TABLE 7. ESTIMATED PARTICULATE EMISSIONS - IRON AND STEEL INDUSTRY

Process	Total particulate controlled emission factor		Particulate emissions for 1974-1989* (10^6 lb/yr)	
	lb/ton of product	Change in emission factor	1974**	1989-1974*
Base case: BOP with no off-gas recovery	0.52	-	69.2	31.2
• Off-gas recovery	0.26	- 0.26		15.6
Base case: Blast furnace	1.5	-	150.0	67.5
• Blast furnace with external desulfurization	1.8	+ 0.3		81.0
Base case: Wet quenching of coke	1.3	-	80.6	58.5
• Dry quenching of coke	1.2	- .1		54.0
Base case: Steelmaking				
• Coke oven, BF, BOP route	3.4	-	452.2	204.0
• Direct reduction, EAF route	1.1	- 2.3		66.0

* Based on production in 1989 being 45 x 10^6 tons of coke, 45 x 10^6 tons of iron, and 60 x 10^6 tons of steel greater than in 1974.

(continued)

TABLE 7. (continued)

** Estimated 1974 emissions (based on the emission factor of 1.3 lb/ton of coke) are $1.3 \times 62 \times 10^6 = 80.6 \times 10^6$ lb from coke production; estimated 1974 emissions (based on the emission factor of 1.5 lb/ton of iron) are $1.5 \times 100 \times 10^6 = 150 \times 10^6$ lb from iron production; and estimated 1974 emissions (based on emission factors of 0.52 lb/ton of steel and 3.4 lb/ton of steel) are $0.52 \times 133 \times 10^6 = 69.2 \times 10^6$ lb or $3.4 \times 133 \times 10^6 = 452.2 \times 10^6$ lb from BOF furnaces and from steelmaking process, respectively.

Basic Oxygen Process (BOP) for Steelmaking

Base Case Process - BOP Off-Gas/No Recovery--

BOP off-gas consist largely of carbon monoxide and thus are highly combustible. In conventional practice, no provision is made to prevent air from contacting the flue gas, and thus the hot gases combust spontaneously in the gas-collecting hood.

About 55 lb of particulate/ton of steel are produced in the BOP (Volume III, page 23). The dust particules are oxidized due to combustion. Approximately 25% of the particles are below 1 micron in size. Either electrostatic precipitator or a wet scrubber can be used to control such emissions. The pressure drop in the scrubber is 40 to 65 inches of water and the cleaned gas contains less than 0.05 gr/scf (grains/standard cubic foot), equivalent to about 0.51 lb/ton of steel (EPA, 1975). Efficiencies of electrostatic precipitators and scrubbers are comparable.

Electricity consumption in the base case process is about 14 kWh/ton of steel (Volume III, page 28). Estimated emissions from a power boiler are 1.20 lb/ton of steel with no control, and 0.01 lb/ton of steel with control to meet the NSPS.

Process Option - BOP Off-Gas Recovery--

In this alternative, air infiltration in the hood, which caused combustion of the hot gas in the base case process, is prevented by a closely spaced hood. The gas--after cooling and cleaning--is available as gaseous fuel for general-purpose use. (A detailed description of the process is given in Volume III, page 19.)

In this non-combustion alternative, the dust is composed mainly of FeO, magnetite and small amounts of metallic iron. Because FeO and magnetite agglomerate more easily than hematitie (present in the base case process as the result of spontaneous combustion), the dust particles in this alternative are larger than those emitted from the base case process. A particle-size distribution with 9% of the particles smaller than 5 microns for the off-gas system has been reported (Volume III, page 24). It is not possible to recover 100% of the gas because of the operating conditions (cyclic operation and the presence of combustible gas). Nevertheless, the estimated particulate control efficiency for the system is 99.5%, so that controlled emissions are estimated to be about 0.25 lb/ton of steel. The size of the control equipment in this alternative is smaller than that in the base case process because the prevention of air infiltration results in a smaller flue gas volume.

Presence of carbon monoxide in the flue gas creates fire and explosion hazards not present in the base case process. This makes the electrostatic precipitator system unsuitable for the collection of the carbon monoxide off-gas in the alternative process.

The electricity consumption in this alternative process is about 8 kWh/ton of steel (Volume III, page 27). Estimated emissions from a power boiler are 0.67 lb/ton of steel with no control, but would remain 0.01 lb/ton of steel with control to meet the NSPS.

Blast Furnace (BF)

Base Case Process--

The base case process includes a blast furnace and a gas-cleaning system. The gas-cleaning device (cyclone and venturi scrubber) is considered part of the process equipment, because it generates a low-Btu fuel gas. The exhaust gas from the scrubber contains particulates consisting of 35 to 50 percent iron, 4 to 14 percent carbon, 8 to 13 percent silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials. Controlled emissions are reported to be 1.5 lb/ton of steel (EPA 1975). because the clean gas is valuable, the control equipment is considered to be a part of the system.

Electricity consumed in the base case process is 25 kWh/ton of hot metal (Volume III, page 44). Estimated emissions from a power boiler are 2.1 lb/ton of hot metal with no control, and 0.03 lb/ton of hot metal with control to meet the NSPS.

Process Option - Blast Furnace with External Desulfurization--

In the base case process, blast furnace sulfur content is completely controlled by adding limestone to form a sulfur-bearing slag and by limiting the sulfur content of the metallurgical coke. Addition of an external desulfurization step is an alternative method of controlling the sulfur content of blast furnace hot metal. External desulfurization is achieved by injecting sulfur-reacting reagents (e.g., calcium or magnesium compounds carried in an inert gas such as nitrogen) into a high-sulfur, hot-metal produced in a blast furnace. These compounds form a sulfide slag that is skimmed off prior to charging the hot metal to the BOP. Use of external desulfurization either permits limestone and coke ratios to be reduced, or allows the sulfur content in the coke to be increased without increasing the limestone charge to the furnace, which has other disadvantages. (A detailed description of this process is given in Volume III, page 29.)

Addition of the external desulfruization step results in an additional emission source. Based on the gas flow rate of 26,500 acfm for 50% of the time (Volume III, page 35) from a facility with annual production rate of 2.6×10^6 ton/yr, the gas flow rate is at 3,000 actual cubic ft/ton of hot metal from the external desulfurizer at an estimated 650).

The particulate loading in the gas is 0.0025 lb/scf (Volume III, page 35), which is equal to 5.7 lb/ton of hot metal. The particulates consist of iron oxide, unreacted desulfurizer, and produce slag and result mostly from entrainment rather than condensation of vaporized metal compounds. Therefore, the particulates are larger than those from the BOP or the blast furnace without external desulfurization. A venturi scrubber with medium pressure drop can be used for this control application. Estimated collection efficiency is 95 percent, so the controlled emissions are about 0.25 lb/ton of hot metal.

Therefore, the uncontrolled emissions from this alternative, including the blast furnace, are 7.2 lb/ton of hot metal, and the controlled emissions are 1.78 lb/ton of hot metal.

Electricity consumption in this alternative is the same as that in the base case process, so power boiler emissions are identical.

Wet Quenching of Coke

Base Case Process--

The base case process includes pushing of coke from the coke oven and wet quenching. A detailed description of the process is given in Volume III, page 48. When the coke is pushed from the coke oven, convection currents carry off the dust from the coke. If there is uncoked material, combustion of its volatile constituents will create additional smoke and set up stronger gas flows, which cause additional emissions. Uncontrolled coke pushing emissions have been reported to be 0.6 lb/ton of coal (EPA 1975).

Control methods include wet scrubbing. The controlled emissions cannot be estimated, because no data are available.

Quench towers represent the other source of particulate emissions. Recent data indicate emission rates of about 1.5 lb/ton of coal for operations using fresh water with no dissolved solids (TDS = 0), increasing linearly to 5 lb/ton of coal for operations using water with TDS = 20 lb/ton of water (Ref. 1). Installation of baffles in the quench tower is claimed to remove solid particulates with about 50 percent collection efficiency.

The total uncontrolled emissions are 2.1 lb/ton of metal, based on use of fresh water in the quench tower. The controlled emissions are estimated at less than 1.31 lb/ton of metal. The electricity consumption in this process is very low so power boiler emissions are negligible.

Process Option - Dry Quenching of Coke--

In dry quenching of coke, the coke is cooled by an inert gas stream. The sensible heat transferred to the inert gas can then be partially

recovered for reuse. (A detailed description of the process is given in Volume III, page 48.)

Coke dust could still be discharged to the atmosphere during the coke-pushing operation. The emission loads are expected to be approximately the same as those in the base case process. In addition, several sources in the dry quenching operation emit fugitive or minor particulate emissions. However, such emissions cannot be quantified, because data are not available. The dry quench system is basically a closed system and control of particulates must be considered inherent in the process.

PETROLEUM REFINING INDUSTRY

Base Case Process - 1985 Refinery

A description of the petroleum refining industry is presented in Volume IV, page 9. In assessing the impact of process changes in the refining industry, a 1985 refinery configuration was used as a base case. The reasons for using this approach are given in Volume IV, page 22. Three configurations were selected to represent the local conditions: East Coast, Gulf Coast, and West Coast.

East Coast Refinery

Base Case Process--

The base case East Coast refinery is described in Volume IV, page 23. The energy intake in this refinery is 1.31×10^{12} Btu/day and production is equivalent to 1.19×10^{12} Btu/day (Volume IV, page 35). The energy intake and production are assumed for the year 1985.

The major airborne pollutants emitted by refineries are identified in Volume IV, page 22. The emission factors summarized in EPA 1975 were used to determine particulate emissions from the base case refinery. The particulate emissions estimated in Volume IV, page 24, are about 880 lb/day from gas-fired process heaters and boilers (uncontrolled), 8,100 lb/day from oil-fired heaters and boilers (uncontrolled), and 2,800 lb/day from fluid catalytic crackers (controlled). The total emissions (11,780 lb/day) are equivalent to about 9.9 $lb/10^9$ Btu of refinery output. The above emissions from the heaters and boilers are not controlled, while those from the fluid catalytic crackers are controlled in electrostatic precipitators.

The uncontrolled emissions from the fluid catalytic crackers are estimated to be 15,100 lb/day. The total uncontrolled particulate emissions (24,080 lb/day) from the refinery are equivalent to about 20 $lb/10^9$ Btu of refinery output.

Based on the electricity consumption of 8.9×10^9 Btu/day and the steam consumption of 8.1×10^9 Btu/day (Volume IV, page 35), estimated emissions from the power boiler are 115 lb/10^9 Btu of refinery output with no control, and 1.4 lb/10^9 Btu of refinery output with control to meet the NSPS.

Process Option 1 - Direct Combustion of Asphalt in Process Heaters and Boilers--

A detailed description for this alternative appears in Volume IV, page 32. Utilizing asphalt for combustion is done primarily to upgrade the overall form value of refinery products, rather than to actually increase overall thermal efficiency within the refinery. Part of the refinery gas (36.6%) and all of the fuel oil are displaced by asphalt. The energy balances for the base case process and the alternative are summarized in Volume IV, page 35.

In the alternative process, particulate emissions are increased because of higher emissions from asphalt combustion compared to those from gas or oil combustion. The particulate emissions from asphalt combustion are about 12,000 lb/day (Volume IV, page 38). The emissions from the gas-fired heaters and boilers are decreased from 8,100 lb/day (in the base case process) to 600 lb/day because of the reduced consumption of gas. The net increase in emissions in this alternative from the base case process is 4,500 lb/day. The total uncontrolled particulate emissions are about 28,580 lb/day (24.0 lb/10^9 Btu of refinery output) and the controlled emissions are about 16,300 lb/day (13.7 lb/10^9 Btu of refinery output).

Based on the electricity consumption of 8.9×10^6 Btu/day and the steam consumption of 9.7×10^6 Btu/day (Volume IV, page 35), estimated emissions from power boilers are 125 lb/10^9 Btu of refinery output with no control, and 1.6 lb/10^9 Btu of refinery output with control to meet the NSPS.

Process Option 2 - Flexicoking Process Alternative--

Flexicoking is the combination of fluid coking with coke gasification. Although fluid coking is a commercially available technology, there are no commercially operating flexicokers. (A detailed description of the process is given in Volume IV, page 52.)

An additional particulate emission source in the alternative is the fluid coker. However, data on uncontrolled emissions from this source are not available. Exxon claims complete removal of particulates in a control device (Volume IV, page 57). Therefore, controlled emissions are taken to be the same as in the base case process, or about 9.9 lb/10^9 Btu of refinery output.

Based on the electricity consumption of 9.6×10^9 Btu/day and the steam consumption of 7.6×10^9 Btu/day (Volume IV, page 58), estimated

emissions from power boilers are 120 lb/10^9 Btu of refinery output with no control, and 1.5 lb/10^9 Btu of refinery output with control to meet the NSPS.

Gulf Coast Refinery

Base Case Process--

The base case Gulf Coast refinery feedstock configuration for the year 1985 is described in Volume IV, page 23. Total energy input in the base case refinery is 1.31 x 10^{12} Btu/day and production is equivalent to 1.2 x 10^{12} Btu/day. The particulate emissions in the Gulf Coast base case refinery are evaluated in a manner similar to that used for the East Coast base case refinery.

Based on the electricity consumption of 9.2 x 10^9 Btu/day and the steam consumption of 0.7 x 10^9 Btu/day (Volume IV, page 70), estimated emissions from the power boiler are 66 lb/10^9 Btu of refinery output with no control, and 0.83 lb/10^9 Btu of refinery output with control to meet the NSPS.

Based on the uncontrolled emission factor of 242 lb of particulate/10^3 lb of fresh fuel (Volume IV, page 147) and the fuel rate, and the uncontrolled emissions from the heaters and boilers, 9,850 lb/day (Volume IV, page 25), the total uncontrolled emissions are estimated at 29,300 lb/day, equivalent to 24 lb/10^9 Btu of refinery output. Emissions from the heaters and boilers are not controlled and therefore the controlled emissions are estimated at about 13,400 lb/day (Volume IV, page 25), equivalent to about 11 lb/10^9 Btu of refinery output.

Process Opiton - On-site Electric Power Generation by Combustion of Asphalt--

In this process alternative, electric power is generated within the refinery rather than purchased from a local electric utility. The fuel is assumed to be asphalt. A simplified flow sheet for this alternative is shown in Volume IV, page 69.

Generation of electric power within the refinery neither conserves energy nor consumes more energy than when power is purchased, assuming that the on-site and off-site power plants would operate at the same efficiencies. In effect, the form value of the asphalt is upgarded to a higher form value of electric power for refinery use. The design capacity of the generator is 36.5 megawatts (Volume IV, page 77).

Because of on-site power generation, this process alternative will result in increased on-site emissions. Particulate emissions from the power boiler are 1,226 lb/day (Volume IV, page 73), equivalent to about 1.0 lb/10^9 Btu of refinery output. These emissions will have to be controlled to meet the NSPS to about 0.76 lb/10^9 Btu of refinery output. Particulate emissions from the process are not affected (about 24 lb/10^9 Btu of refinery output with no control, and about 11 lb/10^9 Btu of refinery output with control).

Because of the reduced consumption of electricity from an off-site power boiler, estimated emissions from off-site power boilers (coal-fired) are reduced to about 4.7 $lb/10^9$ Btu of refinery output with no control, and 0.05 $lb/10^9$ Btu of refinery output with control to meet the NSPS. The total estimated particulate emissions from on-site and off-site power boilers are about 5.7 $lb/10^9$ Btu of refinery output with no control and 0.81 $lb/10^9$ Btu of refinery output with control to meet the NSPS.

West Coast Refinery

Base Case Process--

The West Coast base case refinery feedstock configuration for the year 1985 is described in Volume IV, page 23. Total energy input in the base case refinery is 1.0×10^{12} Btu/day and production is equivalent to 0.95×10^{12} Btu/day.

Particulate emissions in this base case process are evaluated in a manner similar to that used for both the East Coast and Gulf Coast base case refineries. Uncontrolled emissions from the refinery are estimated at about 20,000 lb/day, equivalent to about 21 $lb/10^9$ Btu of refinery output. Controlled emissions are estimated at about 12,500 lb/day (Volume IV, page 26), equivalent to about 13 $lb/10^9$ Btu of refinery output.

Estimated emissions from power boilers are about 80 $lb/10^9$ Btu of refinery output with no control, and about 1.0 $lb/10^9$ Btu of refinery output with control to meet the NSPS.

Process Option - Hydrocracking of Heavy Bottoms--

In this option, asphalt is used as a feedstock for a hydrocracking process (such as H-oil or Isomax) in which the heavy bottoms are converted to lighter fuel oil and gaseous products. The H-oil process was chosen to exemplify a heavy-ends hydrocracking process. (A detailed description of the process is given in Volume IV, page 43.)

Because asphalt is used for combustion to replace hydrogen (used in the base case process), the addition to base case particulate emissions from process is 674 lb/day (Volume IV, page 48). Thus, total uncontrolled particulate emissions are about 20,675 lb/day, equivalent to about 22 $lb/10^9$ Btu of refinery output. The controlled emissions are estimated at about 13,175 lb/day, equivalent to about 14 $lb/10^9$ Btu of refinery output. Particulate emissions from power boilers in this alternative are the same as those for the base case process.

Process Option - High-Purity Hydrogen Production via Partial Oxidation of Asphalt--

This alternative is based on the production of high-purity hydrogen for hydrotreating from vacuum bottoms, using a partial oxidation process. The feedstock freed up by this approach would then be available for sale

outside the refinery in the form of pipeline gas or naphtha. A detailed process description is given in Volume IV, page 78. Particulate emissions from the process and power boilers in this alternative are the same as for the base case process.

Summary

The uncontrolled and controlled emission factors for petroleum refining are shown in Table 8. As given in the table, the particulate emissions in the alternative process are comparable to those in the corresponding base case processes, except for the direct combustion of asphalt in process heaters and boilers. The emissions in this alternative are 35% higher than those in the base case process. The particulate emissions from the processes studied are shown in Table 9.

However, with implementation of available control technology, the difference becomes slight enough that problems with praticulates should not have a significnat impact on the industry's selection of alternative processes in the future. It is also not expected that the character of the particulate emissions will be sufficiently different to imporve or complicate removal. The one exception may be the use of direct combustion of asphalt which would result in a 5% increase (hypothetically) in emissions from 424 x 10^6 lb in 1974 with the base case to 453 x 10^6 lb in 1989 if the option is implemented only for the incremental production.

It may also be of interest to point out that the uncontrolled emissions from the power plant are typically much larger than process emissions. Yet, efficiency of control is much higher for the power plant so that the processes account for the major portion of the controlled emissions.

PULP AND PAPER INDUSTRY

Chemical Pulp

Base Case Process - Kraft Pulping--

The base case process selected for chemical pulp was the Kraft process, which includes cooking of wood chips at an elevated temperature and pressure in a digester. When cooking is completed, the contents of the digester are forced into a blow tank. The major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp then enters the initial stage of washing. From the blow tank the pulp passes through the knotter where chunks of wood are removed. The pulp is then washed and bleached before being pressed and dried into the finished product.

It is economical to recover both the inorganic cooking chemicals and the heat content of the spent liquor which is separated from the cooked pulp in the blow tank. Recovery is accomplished by first concentrating the liquor to a level that will support combustion, and then feeding it to a furnace (recovery boiler) where heat and chemical recovery take place.

TABLE 8. ESTIMATED PARTICULATE EMISSION FACTORS - PETROLEUM REFINING INDUSTRY

Process	Emission factor[a] - no control (lb/10^9 Btu of refinery output)			Emission factor[a] - with control (lb/10^9 Btu of refinery output)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: East Coast refinery	20.0	115.0	135.0	9.9	1.4	11.3	91.6
• Direct combustion of asphalt in process heaters and boilers	24.0	125.0	149.0	13.7	1.6	15.3	89.7
• Flexicoking	N.A.	120.0	N.A.	9.9	1.5	11.4	N.A.
Base case: Gulf Coast refinery	24.0	66.0	90.0	11.0	.83	11.8	86.9
• On-site electric power by combustion of asphalt	24.0	5.7	29.7	11.0	.81	11.8	60.3
Base case: West Coast refinery	21.0	80.0	101.0	13.0	1.0	14.0	86.1
• Hydrocracking of heavy bottoms	22.0	80.0	102.0	14.0	1.0	15.0	85.3
• High-purity hydrogen production via partial oxidation of asphalt	21.0	80.0	101.0	13.0	1.0	14.0	86.1

[a]Emissions reported as lb particulate/10^9 Btu of refinery output.

TABLE 9. ESTIMATED PARTICULATE EMISSIONS - PETROLEUM REFINING INDUSTRY

Process	Emission factor (10^9 Btu of refinery output)	Change in emission factor	Particulate emissions (10^6 lb/yr) 1974	Particulate emissions (10^6 lb/yr) 1989-1974[a]
Base case: East Coast refinery	11.3	--	339.0[b]	84.8[a]
• Direct combustion of asphalt in process heaters and boilers	15.3	+ 4.0	--	114.8
• Flexicoking	11.4	+ .1	--	85.5
Base case: Gulf Coast refinery[b]	11.8	--	354.0[b]	88.5
• On-site electric power by combustion of vacuum bottoms	11.8	0	--	88.5
Base case: West Coast refinery[b]	14.0	--	420.0[b]	105.0
• Hydrocracking of heavy bottoms	15.0	+ 1.0	--	112.5
• High purity hydrogen production via partial oxidation of asphalt	14.0	0	--	105.0

[a]Based on incremental national production from 1974 to 1989 equal to 7.5 quads (7.5×10^{15} Btu) multiplied by emission factor assuming no retirement of existing facilities.

[b]Estimated 1974 emissions, based on the total emission factors and production of 30 quads are 339×10^6 lb, 354×10^6 lb and 420×10^6 lb for East Coast, Gulf Coast and West Coast models, respectively.

Uncontrolled particulate emissions from the Kraft pulp process include 130 lb/ton of pulp from the recovery boiler, 5 lb/ton of pulp from the smelt tank, 18 lb/ton of pulp from the on-site power boiler, and 45 lb/ton of pulp from the lime kiln (Volume V, page 172). Total uncontrolled process emissions are therefore 180 lb/ton of pulp, and on-site power boiler emissions are 18 lb/ton of pulp.

The U.S. Envionmental Protection Agency's standards for new Kraft pulp mills are presently at the proposal stage. The proposed standards limit particulate emissions to 2.0 lb/ton of pulp from the recovery boiler, 0.55 or 1.07 lb/ton of pulp from the gas- or oil-fired lime kilns, respectively, and 0.15 lb/ton of pulp from the smelt tank. Therefore, total controlled process emissions should be less than 3.2 lb/ton of pulp.

Present control methods used are scrubbers or electrostatic precipitators for recovery boilers and lime kilns, and packed-bed or low-energy scrubbers for smelt tanks. It is these technologies which are used to reach the proposed standards.

Combination boilers or bark boilers are used as on-site power boilers in the pulp industry. The air pollution control system for these boilers consists of a mechanical collector followed by an electrostatic precipitator or a scrubber. On-site power boiler capacity is about 5×10^6 Btu/ton of pulp (Volume V, page 57). Controlled boiler emissions are estimated at 0.5 lb/ton of pulp (uncontrolled emissions are 18 lb/ton of pulp). About 140 kWh/ton of pulp electricity is credited in the process (Volume V, page 57). The particulate emissions from utility power boilers which are offset by this credit are estimated at about 12 lb/ton of pulp with no control, and 0.15 lb/ton of pulp with control to meet the NSPS. Therefore, total emissions from both on-site and off-site power boilers are estimated at 6 lb/ton of pulp with no control, and 0.35 lb/ton of pulp with control to meet the NSPS.

Process Option 1 - Alkaline-Oxygen Pulping--

The alkaline-oxygen (A-O) pulping process is receiving attention in the industry, because of its potential for a non-sulfur cooking step which would eliminate the air pollution due to sulfur compounds. The steps in the A-O process include an alkaline treatment to soften the wood chips, mechanical disintegration, and treatment with oxygen under alkaline conditions to remove most of the lignin, followed by the last three stages of the conventional multistage bleaching sequence: chlorine dioxide, caustic extraction, and chlorine dioxide. (A detailed description of the process is given in Volume V, page 84.)

The uncontrolled emissions from the alternative process include 110 lb/ton of pulp from the recovery boiler, 2 lb/ton of pulp from the smelt tank, and 19 lb/ton of pulp from the lime kiln (Volume V, page 172). Therefore, total particulate emissions are 131 lb/ton of pulp. The particulate control methods used for this alternative are the same as

those for the base case process. Controlled emissions are estimated at less than 3.2 lb/ton of pulp, or the same as those in the base case process.

Uncontrolled emissions from on-site power boilers are 15 lb/ton of pulp (Volume V, page 172). Controlled emissions are estimated at about 0.42 lb/ton of pulp. About 50 kWh/ton of pulp electricity are credited in the process (Volume V, page 86). The particulate emissions from utility power boilers which are offset by this credit are estimated at about 4 lb/ton of pulp with no control, and 0.05 lb/ton of pulp with control to meet the NSPS. Therefore, total emissions from both the on-site and off-site power boilers are estimated at 11 lb/ton of pulp with no control, and 0.37 lb/ton of pulp with control to meet the NSPS.

Process Option 2 - Rapson Effluent-free Kraft Pulping--

A number of changes in the base case pulping process have been made to eliminate effluents in the modified process, called the Rapson effluent-free Kraft process. (It is described in detail in Volume V, page 95.) The particulate emission control methods and controlled emissions for the Rapson process are the same as those for the base case process.

Uncontrolled emissions from on-site power boilers are estimated at about 18 lb/ton of pulp. Controlled emissions are estimated at 0.2 lb/ton of pulp. On-site power boiler capacity is sufficient to meet the steam and electricity requirements of this alternative process.

Newsprint Pulp

Base Case Process - Refiner Mechanical Pulping (RMP) Route for Newsprint Pulp--

RMP is a mechanical pulping process that itself is an improvement over the conventional groundwood process. Wood chips, sawdust, and shavings from swamills or plywood mills can be used as raw materials for the RMP process, but such materials cannot be used as raw materials for the groundwood process. The wood particules are reduced in a pressurized disc refiner which consists of two circular metal plates that generally rotate in opposite direction. RMP pulp (80%) is used with Kraft pulp (20%) in newsprint paper production with both processes contributing directly or indirectly to process emissions. (A detailed description of the RMP process is given in Volume V, page 60.)

Kraft pulp, contributing 20% of the newsprint pulp in the base case process, involves particulate emissions from the process that were determined to be 180 lb/ton of Kraft pulp with no control and about 3.2 lb/ton of Kraft pulp with controls to meet the proposed NSPS. The total particulate emissions from the power boiler in the Kraft process were estimated at 6.0 lb/ton of Kraft pulp with no control and at 0.35 lb/ton of Kraft pulp with control to meet the NSPS.

There are no major emission sources in the RMP process, except possibly for power boilers, since hydroelectric power is often used. Based on the electricity consumption of 1,475 kWh/ton of RMP pulp and the use of coal-fired power boilers, emissions are estimated at 124 lb of particulate/ton of RMP pulp with no control, and 1.6 lb of particulate/ton of RMP pulp with control to meet the NSPS. Thus with 80% RMP pulp in newsprint production, the RMP process power boilers contributes 1.28 (=0.2 x 0.35) lb of particulate emissions giving total boiler emissions of 1.35 lb particulates/ton RMP based newsprint pulp. Based on the above, the total process emissions are estimated to be all derived from the 20% pulp contribution by the Kraft process which account for 36 lb particulate/ton of newsprint pulp with no control and 0.64 lb/ton of newsprint pulp with control to meet NSPS. The power boiler emissions derived from the RMP process and Kraft process are calculated at about 99.3 lb/ton of newsprint paper with no control and at about 1.35 lb/ton of newsprint paper with control to meet NSPS. Thus, total controlled emissions are estimated to be 1.99 (+ 0.64 + 1.35) lb particulate/ton of newsprint which has been rounded to 2.0 lb particulate/ton of newsprint in Table 10.

Process Option 1 - Thermo-Mechanical Pulping (TMP)--

The TMP process is similar to the base case process (RMP process), except the wood particles are preheated to 130°C for a short period and then reduced to fibers in a pressurized disc refiner.

For production of newsprint, 0.95 ton of TMP pulp and 0.05 ton of Kraft pulp are used per ton of newsprint pulp. Again particulate emissions from the process are derived from the contribution from Kraft pulping.

With 5% Kraft pulp, process particulate emissions are estimated from the information derived above to be 0.05 x 180 = 9 with no control and 0.05 x 3.2 = .16 lb/ton of newsprint with control.

As in the base case RMP process, there are not major emission sources in the TMP process, except for power boilers. With electric energy generated by a power boiler, emissions are the same as those in the base case RMP process, namely 124 lb/ton of TMP pulp with no control and 1.6 lb/ton of RMP pulp with control. Controlled emissions from the power boilers are calculated to be 0.95 x 1.6 = 1.52 lb particulate/ton of newsprint pulp from the TMP process and 0.05 x 0.35 = 0.0175 lb particulate/ton from the Kraft process. This sums to about 1.54 lb particulate/ton of newsprint pulp. Total controlled emissions are thus estimated to be .06 + 1.54 = 1.70 lb particulate/ton of newsprint pulp.

Process Option 2 - De-inking of Old Newsprint for Newsprint Manufacture--

The de-inking of old newsprint for newsprint manufacture is a well-established commercial practice. A detailed description of the process is given in Volume V, page 113.

TABLE 10. ESTIMATED PARTICULATE EMISSION FACTORS - PULP AND PAPER INDUSTRY

Process	Emission factor - no control (lb/ton of pulp*)			Emission factor - with control (lb/ton of pulp)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: Kraft pulp	180.0	6.0	186.0	3.2	0.35	3.6	98.1
• Alkaline-oxygen pulping	131.0	11.0	142.0	3.2	0.37	3.6	97.5
• Rapson effluent-free Kraft	180.0	18.0	198.0	3.2	0.2	3.4	98.3
Base case: Refiner-mechanical pulping (80% and Kraft 20%)	36.0	99.3	135.3	0.64	1.35	2.0	98.5
• Thermo-mechanical pulping (95% and Kraft 5%)	9.0	118.1	127.1	0.16	1.54	1.71	98.9
• De-inking of old newsprint for newsprint manufacture	0	49.0	49.0	0	0.61	0.61	98.8

*Air-dry basis.

There are no major emission sources in this alternative except for power boilers. Based on the energy consumption of 6.1×10^6 Btu/ton of newsprint pulp (Volume V, page 115), particulate emissions from the power boilers are estimated at 49 lb/ton of pulp with no control, and 0.61 lb/ton of pulp with control to meet the NSPS. In this case, it is presumed that all energy is purchased and no energy value is credited from waste.

Summary

Estimated particulate emission factors for the pulp and paper industry are shown in Table 10. The uncontrolled emissions in the A-O pulping alternative process are about 25% lower than for the base case process. The uncontrolled emissions in the Rapson process are comparable to those in the Kraft base case process. The uncontrolled emissions in the alternative processes for newsprint production are about 30% lower than the base case process.

The final or controlled particulate emission problems in all the processes (except de-inking of old newsprint for newsprint manufacture) are similar, and control methods used in these processes are the same. (Emissions in the manufacture of newsprint are present from the Kraft process only.) The controlled emissions in the alternative processes for the manufacture of newsprint are about 30 to 50% lower than those in the base case process. The estimated particulate emissions in the pulp and paper industry are shown in Table 11.

Thus, while uncontrolled emissions are lower in the A-O process, once conventional technology is implemented for control, the benefit decreases. Whether the reduced requirement to achieve that level is significant is, however, doubtful and it is unlikely that particulate levels or control would be a factor in selecting a process. Elimination of the sulfur (TRS) energy saving would be much more important, the latter more true for the Rapson process.

The same statements are related to Kraft vs A-O or Rapson pulp use in either RMP- or TMP-based newsprint. However, de-inking of existing newsprint offers even less particulate emissions and conserves more energy.

OLEFIN INDUSTRY

Ethylene Production

Base Case Process - Ethylene Production Based on Ethane and Propane Cracking--

The base case technology selected for the assessment of the domestic olefin industry was ethane and propane (E-P) cracking. (A detailed description of the process of producing ethylene from ethane and propane is given in Volume VI. page 16.)

TABLE 11. ESTIMATED PARTICULATE EMISSIONS - PULP AND PAPER INDUSTRY

Process	Total controlled particulate emission factor (lb/ton of pulp)	Change in emission factor	Particulate emissions (10^6 lb/yr) 1974	1989-1974*
Base case: Kraft pulp	3.6	-	57.6	62.3
• Alkaline-oxygen pulping	3.6	0		62.3
• Rapson effluent-free Kraft	3.4	-0.2		59.0
Base case: Refiner mechanical pulping	2.0	-	7.8	3.4
• Thermo-mechanical pulping	1.4	-0.6		2.4
• De-inking of old newsprint for newsprint manufacture	0.61	-1.39		1.0

* Based on emissions in 1989 being 17.3×10^6 tons of pulp and 1.7×10^6 ton of newsprint greater than in 1974.

The major source of particulate emissions in an ethylene plant is the intermittent decoking of process furnaces. High-temperature steam is used to react with or otherwise loosen and remove coke from the furnace coils. A typical decoking cycle lasts for 16 hours. Since decoking of furnaces is required after 40 days, even the largest plants should be easily served by a single operating decoking scrubber system. In such a control system, a spray tower is used to scrub out the particulates.

A second source of particulate emissions is the regeneration of the acetylene converter. This operation is similar to furnace decoking in that steam or air is used to burn out residual oil and carbon deposits from the converter. The regeneration is carried out once or twice a year and takes about 48 hours. The same scrubber control system used for the decoking operation can be used to control emissions from the regeneration of the acetylene converter.

Uncontrolled intermittent emissions from the decoking operation are 41.6 lb/hr from an ethylene plant having a capacity of 1.1×10^9 lb/yr (Volume VI, page 34). Data on the uncontrolled intermittent emissions from the regeneration of the converter are not available, but may be comparable to those from the decoking operation. The emissions are generated for an average of 955 hr/yr from the above two sources (Volume VI, page 51). Therefore, uncontrolled emissions are estimated at 0.072 lb/ton of ethylene.

Controlled intermittent emissions from the decoking operation are 0.9 lb/hr. Data on the controlled emissions from the regeneration of the converter are not available, but may be comparable to those from the decoking operation. The estimated controlled emissions are 0.002 lb/ton of ethylene.

Fuel is consumed in the process heaters at a rate equivalent to 7,800 Btu/lb of ethylene (Volume VI, page 28). Estimated uncontrolled emissions from this source -- based on the emission factor of 10 lb/10^6 cu ft of gas (AP-42) -- are 0.15 lb/ton of ethylene. Because of the low emission rate, these emissions are not controlled. Consequently, total uncontrolled emissions from the process are 0.22 lb/ton of ethylene, and controlled emissions are estimated at 0.15 lb/ton of ethylene with the decoking and converting operations contributing a negligible quantity.

The electricity consumption in the base case process is equivalent to 900 Btu/lb of ethylene, and the steam consumption is equivalent to 8,000 Btu/lb of ethylene. It is assumed that steam is generated in an on-site natural gas boiler and that electricity is purchased. The estimated emissions from the on-site power boiler are 0.15 lb/ton of ethylene. The estimated emissions from off-site power boilers (presumed to be coal-fired) are 14.4 lb/ton of ethylene with no control, and 0.18 lb/ton of ethylene with control to meet the NSPS. The total emissions from the boilers are estimated at about 14.6 lb/ton of ethylene with no control, and about 0.33 lb/ton of ethylene with control to meet the NSPS.

Process Option 1 - Ethylene from the Pyrolysis of Naphtha--

Pyrolysis of naphtha already accounts for 7% of domestic ethylene production and is the predominant technology used in Europe and Japan. (This process alternative is described in Volume VI, page 22.)

As with the base case, the major sources of particulates during the manufacture of ethylene from heavy feedstocks are the intermittent decoking of process furnaces and regeneration of the converters. The amount of coke built up within a process furnace at the time decoking is required is the same for heavy feedstocks as it is for the base case. However, the rate of buildup in the furnace is higher because the heavier feedstocks produce more coke. Also, the quantity of feedstocks processed is increased in this alternative. Hence, the amount of steam required per decoking operation is the same as for the base case; the control equipment required will be the same as that for the system described in the base case process.

The uncontrolled emission rate to the scrubber (during operation) is the same as in the base case process; viz., 41.6 lb of particulate/hr. The scrubber is operated an average of 1,788 hr/yr (Volume VI, page 51). Estimated uncontrolled emissions are 0.13 lb/ton of ethylene. The controlled emissions from the scrubber are higher, about 1.3 lb/hr, for this alternative than for the base case process. The estimated emissions from the scrubber are equivalent to 0.004 lb/ton of ethylene.

Fuel is consumed in the process heaters at a rate equivalent to 10,300 Btu/lb of ethylene. Estimated emissions from this source - based on the emission factors of 10 lb/10^6 cu ft of gas (AP-42) - are 0.20 lb/ton of ethylene. There is no control requirement at this time for this source.

Total uncontrolled emissions from the process are 0.33 lb/ton of ethylene with no control, and controlled emissions are estimated at 0.20 lb/ton of ethylene.

The electricity consumption in the alternative process is equivalent to 1,100 Btu/lb of ethylene and the steam consumption is equivalent to 6,200 Btu/lb of ethylene. It is assumed that steam is generated in an on-site oil-fired boiler and that electricity is purchased. It is expected that oil-fired steam generators will be used in this process consistent with the philosophy of switching from natural gas to heavy fuel stocks. Estimated emissions -- based on the emission factor of 3 lb/1,000 gal of oil burned in the boiler (AP-42) -- are 0.25 lb/ton of ethylene. Estimated emissions from off-site power boilers are 17.6 lb/ton of ethylene with no control, and 0.22 lb/ton of ethylene with control to meet the NSPS. Total emissions from boilers are estimated at 17.9 lb/ton of ethylene with no control, and 0.47 lb/ton of ethylene with control to meet the NSPS.

Process Option 2 - Ethylene from the Pyrolysis of Gas-Oil--

Several plants now being constructed will use gas-oil as feed. The design of such plants is well established at the commercial level and the practice is clearly going to become common as ethylene producers move to assure themselves of some flexibility in their choice of feedstock. (A process description for ethylene production based on gas-oil is given in Volume VI, page 27.)

The particulate emission sources and emission control methods in this alternative are the same as in the base case process. The uncontrolled intermittent emission rate in the alternative process is the same as in the base case process; however, the number of hours per year during which emissions are produced is increased to 3,360. The reasons for the increase in the hours is due to more build-up of coke when gas-oil is used as a feedstock, and a higher quantity of feedstock must be processed as compared to that in the base case process. The uncontrolled emissions are estimated at 0.25 lb/ton of ethylene. The controlled emission rate is 2.0 lb/hr and is equivalent to 0.012 lb/ton of ethylene.

Fuel is consumed in the process heaters at a rate equivalent to 14,700 Btu/lb. Estimated emissions from this source -- based on the emission factor of 10 lb/10^6 cu ft of gas (AP-42) -- are 0.28 lb/ton of ethylene.

Total uncontrolled emissions from the process are 0.53 lb/ton of ethylene, and the controlled emissions are estimated at 0.29 lb/ton of ethylene.

Electricity consumption in the alternative process is equivalent to 1,500 Btu/lb of ethylene, and steam consumption is equivalent to 5,500 Btu/lb of ethylene. It is assumed that steam is generated in an on-site oil-fired boiler, and that electricity is purchased. The estimated emissions based on the emission factor of 3.0 lb/1,000 gal of oil burned in the on-site boiler are 0.22 lb/ton of ethylene. The estimated emissions from off-site power boilers are 24 lb/ton of ethylene with no control, and 0.30 lb/ton of ethylene with control to meet the NSPS. Total emissions from the boilers are estimated at about 24 lb/ton of ethylene with no control, and 0.52 lb/ton of ethylene with control to meet the NSPS.

Summary

Uncontrolled and controlled particulate emission factors in the olefin industry are summarized in Table 12, and estimated particulate emissions are summarized in Table 13. The majority of the total emissions -- more than 65% of the controlled emissions and more than 95% of the uncontrolled emissions -- come from the power boilers. These emissions are well controlled and therefore these processes have high overall particulate collection efficiency (> 95%). The emission sources

TABLE 12. ESTIMATED PARTICULATE EMISSION FACTORS - OLEFIN INDUSTRY

Process	Emission factor - no control (lb/ton of ethylene)			Emission factor - with control (lb/ton of ethylene)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case:							
Ethylene from ethane and propane	0.22	14.6	14.8	0.15	0.33	0.48	96.7
• Ethylene from naphtha	0.33	17.9	18.2	0.20	0.47	0.67	96.3
• Ethylene from gas-oil	0.53	24.0	24.5	0.29	0.52	0.81	96.7

TABLE 13. CONTROLLED ESTIMATED PARTICULATE EMISSIONS - OLEFIN INDUSTRY

Process	Total controlled particulate emission factor (lb/ton of product)	Change in emission factor	Particulate emissions (10^6 lb/yr) 1974	1989-1974*
Base case: Ethylene from ethane and propane	0.48	--	6.2	13.5
• Ethylene from naphtha	0.67	+ 0.19	--	18.9
• Ethylene from gas-oil	0.81	+ 0.33	--	22.8

*Based on production in 1989 being 28.2 x 10^6 ton greater than in 1974.

and the emission control methods in these processes are similar. Both the uncontrolled and controlled emission factors in the alternative processes are higher than those in the base case process (Table 12) when based on ethylene production; however, if the emission factors are compared on the basis of tons of feedstock, those in the alternative processes are lower than those in the base case process.

Although the actual quantities of particulate emissions are not great, the particulate emissions in the year 1974, based on the ethane and propane cracking, are 6.2×10^6 lb/year (ethylene production, 13.2×10^6 ton/yr) and will increase by the year 1989 to 19.7×10^6 lb/yr (ethylene production, 41.2×10^6 ton/yr). If the alternative processes are installed on the incremental production from 1974 to 1989, estimated particulate emissions from the total production of ethylene in the year 1989 based on the naphtha process are 25.1×10^6 lb/yr and based on the gas-oil process are 29.0×10^6 lb/yr. These estimations include emissions of 6.2×10^6 lb/yr in the base case year (1974). The increase in emissions which is attributable to heavier feedstocks is quite significant; however, the alternative processes produce higher quantities of byproducts. Emissions generated from the production of these byproducts when added to the base case process for comparison will alter the impact on particulate emissions; however, this overall impact is not determined in this report.

ALUMINA AND ALUMINUM INDUSTRY

Alumina Production

Base Case Process - Bayer Process--

The Bayer process for producing alumina is based on imported bauxite. The process includes: digestion of ground bauxite, removal of impurities, precipitation of aluminum trihydrate, treatment of spent liquor to regenerate the caustic, and calcination of aluminum trihydrate to produce pot feed alumina. A detailed description of the process is given in Volume VIII, page 106.

Within a Bayer plant, bauxite is ground and digested with caustic to produce sodium aluminate. The major source of emissions during this operation is the ore grinder. The reported particulate emission factor is 6.0 lb/ton of bauxite (EPA 1975). Particulates from the ore grinder are collected in a hood and removed using a high-efficiency particulate collection device, such as an electrostatic precipitator. The expected emissions from a precipitator are 0.12 lb/ton of bauxite (EPA 1975). Low-efficiency wet-collection devices have been used at some plants, but are generally not effective enough to comply with current standards. About 2.4 tons of bauxite are required to produce a ton of alumina (Volume VIII, page 111). Thus estimated uncontrolled particulate emissions are 14.4 lb/ton alumina and controlled are 0.29 lb/ton alumina. After precipitation, alumina trihydrate is calcined in a rotary kiln to produce alumina. Emissions from the kiln are reported

to be 200 lb/ton of alumina (EPA 1975). Particulates from the rotary-kiln calcining operation are removed using a combination of multicyclone and electrostatic precipitators or bag filters. Emissions from the electrostatic precipitator are 4.0 lb/ton of alumina. (EPA 1975)

In addition, emissions result from crushing and calcination of limestone ($CaCO_3$). About 0.133 ton of limestone/ton of alumina is required (Volume VIII, page 111). This amounts to about 0.074 tons CaO/ton alumina. Uncontrolled emissions are reported to be 33 lb/ton of lime from crushing and 200 lb/ton of lime from the kiln. Therefore, uncontrolled emissions are about 17 lb/ton of alumina. Scrubbers or bag filters can be used to control only kiln emissions with a reported collection efficiency of up to 99 percent. Therefore, the controlled emissions are estimated at about 2.6 lb/ton of alumina, which are mostly from the crusher operation.

Total process emissions from the Bayer process are about 232 lb/ton of alumina with no control, and controlled emissions are about 6.9 lb/ton of alumina.

Electricity consumption in the base case process is estimated at 275 kWh/ton of alumina, and steam consumption is estimated as equivalent to 7.33×10^6 Btu/ton of alumina. Particulate emissions from coal-fired power boilers are estimated at 82 lb/ton of alumina with no control, and about 1.0 lb/ton of alumina with control to meet the NSPS.

Process Option 1 - Hydrochloric Acid Ion-Exchange Process--

This process includes dehydration of the raw clay, leaching with hydrochloric acid, separation of residue, purification of the solution by amine ion exchange, crystallization of aluminum chloride, decomposition, and calcination to obtain alumina. (A detailed description of the process is given in Volume VIII, page 23.) No commercial plant embodying this process has ever been built (Volume VIII, page 27); therefore the estimated emissions represent engineering judgment.

It is estimated that this process alternative during grinding and calcining of clay generates as much dust as does bauxite during grinding and initial calcination (Volume VIII, page 29). Therefore, the emissions and the control methods from these sources are the same as those in the base case process. Lime is not used in this alternative, so lime-related emissions are not present. The total process emissions are estimated at 215 lb/ton of alumina with no control, and 4.2 lb/ton of alumina with control.

The electricity consumption in this alternative is 134 kWh/ton of alumina. Estimated emissions from power boilers are 11.3 lb/ton of alumina with no control, and 0.14 lb/ton of alumina with control to meet the NSPS.

Process Option 2 - Nitric Acid Ion-Exchange Process--

This process includes calcining kaolin clay, leaching the calcined clay with hot nitric acid, separating the clay insolubles, removing the iron and other impurities, recovering the alumina by hydrolysis, recovering the nitric acid, and calcining to obtain alumina. This process is presently not used in the industry.

The calcination of beneficiated clay pellets would not generate as much particulate matter as the calcination of bauxite, but particulate emission controls will be required for clay particulates and fly ash, because coal is used in the calcination kiln. Emission factors cannot be calculated because quantitative data are not available.

Electricity consumption in this alternative is 139 kWh/ton of alumina (Volume XIII, page 39). Estimated emissions from power boilers are 11.7 lb/ton of alumina with no control, and 0.15 lb/ton of alumina with control to meet the NSPS.

Process Option 3 - Toth Alumina Process--

This process involves the chlorination of alumina-containing raw materials in the presence of carbon to produce aluminum chloride vapor and other volatile chlorides, which are purified to eliminate other metal chlorides and then oxidized to alumina and chlorine for recycle. (The details of the process are given in Volume VIII, page 39.)

Dehydration of raw clay in a dryer and calcination in a kiln will result in emissions containing particulates. The dryer and kiln will require particulate control devices. Emission factors from these sources cannot be calculated because quantitative data are not available. It can only be presumed that particulate emissions may be comparable to those for the drying and calcination of lime or clay, approximately 200 lb/ton solids.

Electricity consumption in this alternative is 333 kWh/ton of alumina (Volume XIII, page 48). Estimated emissions from power boilers are about 30 lb/ton of alumina with no control, and 0.35 lb/ton of alumina with control to meet the NSPS.

Aluminum Production

Base Case Process - Hall-Heroult Process--

This process involves reduction of alumina to aluminum using electrolytic cells. The existing plants use Soderberg electrodes, while the new plants use prebaked electrodes which consume less energy. A detailed description of the process is given in Volume VII, page 52.

Plants which use Soderberg cells do not require anode furnaces, because the anode is formed from a coke-based paste within the electrolytic cell itself. There are two types of Soderberg cells: horizontal stud and vertical stud. With respect to air pollution control, the primary difference between these two types has to do with the east with which a hood can be placed over a cell to capture emissions. Hood efficiency has been reported to be 50 percent for vertical-stud cells and 80 percent of horizontal-stud cells (Volume VIII, page 136). Uncontrolled emissions in the hood have been reported to be about 98 lb/ton for horizontal-stud cells and 78 lb/ton for vertical-stud cells (AP-42). Wet electrostatic precipitators or venturi scrubbers can be used for particulate control. Controlled emissions from the particulate control device have been reported to be about 7.0 lb/ton for horizontal-stud cells and about 3.0 lb/ton for vertical-stud cells. With respect to hood efficiency, uncontrolled emissions are estimated to be 123 lb/ton for horizontal-stud cells and 156 lb/ton for vertical-stud cells. Total controlled emissions are estimated to be 32 lb/ton for horizontal-stud cells, and 81 lb/ton for vertical-stud cells.

Electricity consumption in the baseline process is 15,600 kWh/ton. Estimated particulate emissions from power boilers are 1,310 lb/ton with no control, and 16.4 lb/ton with control to meet the NSPS.

The emission factor for the prebake anode furnace is 3.0 lb/ton of aluminum, which can be reduced to 0.06 lb/ton of aluminum by self-induced sprays (EPA, 1975). The emission factor for the prebake cell is 81.3 lb/ton of aluminum. Emissions can be controlled by coated filters, electrostatic precipitators, or by dry alumina adsorbers to 1.62 lb/ton of aluminum (EPA, 1975).

Captive efficiency of the hood on the prebake cell is reported to be 95 percent on new cells (Volume VIII, page 136). Therefore, the uncontrolled process emissions from the cell and prebake furnace are estimated at about 89 lb/ton, and the controlled emissions are estimated at about 6.0 lb/ton.

Electricity consumption in the new cells is estimated at 12,000 kWh/ton. Estimated paritculate emissions from power boilers are about 1,010 lb/ton with no control, and about 12.6 lb/ton with control to meet the NSPS.

Process Option 1 - Alcoa Chloride Process--

This process starts with pot feed alumina from the Bayer process. The alumina is converted into aluminum chloride by chlorination in the presence of carbon to form volatile aluminum chloride. This, in turn, is purified and fed to the electrolytic cells to produce molten aluminum. A detailed process description is given in Volume VIII, page 57.

The process emissions include emissions from the dryer calciner and electrolytic cells. Currently, there are no plants in operation, so data on emissions from those sources are not available. The nature of the process is so different that it would be unrealistic to attempt estimates based on the very sparse information available.

Electricity consumption in this process is 10,500 kWh/ton (Volume VIII, page 69). Estimated particulate emissions from power boilers are about 882 lbs/ton with no control, and about 11 lb/ton with control to meet the NSPS.

Process Option 2 - Refractory Hard Metal Cathodes Process--

This process is based on Bayer alumina and uses titanium diboride cathodes instead of conventional carbon cathodes. The cathodes are assumed to be retrofitted in existing large cells to increase production and reduce energy consumption (Volume VIII, page 74). A detailed process description is given in Volume VIII, page 68.

The uncontrolled emissions, emission control system, and controlled emissions from this alternative process are expected to be the same as in the base case process with Soderberg cells. Electricity consumption is estimated at 12,480 kWh/ton (Volume VIII, page 74). Estimated particulate emissions from the power boiler are about 1,050 lb/ton with no control, and about 13.1 lb/ton with control to meet the NSPS.

Process Option 3 - Combination of the Clay Chlorination Process and the Aloca Chloride Process--

This combined process has all of the emission problems of the Toth alumina process, plus some of the problems of the Aloca process. The details of the combined process are given in Volume VIII, page 79. Emissions from this alternative process cannot be estimated, because data are not available for the separate processes. Electricity consumption is estimated at 10,637 kWh/ton (Volume VIII, page 81). Estimated particulate emissions from power boilers are about 895 lb/ton with no control, and about 11.2 lb/ton with control to meet the NSPS.

Summary

Currently, the Hall-Heroult process relies heavily on hydroelectricity ($\sim$ 25%). Since availability of hydroelectric power is projected to be limited, especially for increased production capabilities, the entire study has been carried out assuming fossil fuel-derived power.

The particulate emission factors from the base case and the alternative processes in the alumina and aluminum industry are shown in Table 14. The uncontrolled emission factor in the hydrochloric ion-exchange process for alumina production is about 28% lower than in the corresponding base case process, because the electricity consumption in the alternative process is lower than that in the base case process.

TABLE 14. ESTIMATED CONTROLLED PARTICULATE EMISSION FACTORS - ALUMINA AND ALUMINUM INDUSTRY

Process	Emission factor - no control (lb/ton product)			Emission factor - with control (lb/ton product)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: Bayer	232.0	82.0	314.0	6.7	1.0	7.7	97.5
• Hydrochloric acid ion exchange	215.0	11.3	226.3	4.3	.14	4.4	98.0
• Nitric acid ion exchange	N.A.	11.7	N.A.	N.A.	.15	N.A.	N.A.
• Clay chlorination (toth)	N.A.	30.0	N.A.	N.A.	.35	N.A.	N.A.
Aluminum							
Base case: Hall-Heroult (current practice)	123-156	1310	1433.0-1466.0	32-81	16.4	48.4-97.4	93.3-96.6
• Hall-Heroult (new)	89	1010	1099	6	12.6	18.6	98.3
• Alcoa chloride	N.A.	882	N.A.	N.A.	11	N.A.	N.A.
• Refractory hard metal cathode	123-156	1050	1173-1206	32-81	13.1	45.1-94.1	92.2-96.1
Base case: Bayer and Hall-Heroult (C.P.)	355-388	1392	1747-1780	38.7-89.7	17.4	56.1-105.1	94.1-96.8
• Toth alumina and alcoa chloride	N.A.	895	N.A.	N.A.	11.2	N.A.	N.A.

TABLE 15. ESTIMATED PARTICULATE EMISSIONS - ALUMINA AND ALUMINUM INDUSTRY

Process	Total controlled particulate emission factor (lb/ton of product)	Change in emission factor	Particulate emissions (10^6 lb/yr) 1974**	1989-1974*
Alumina				
Base case:				
Bayer	7.7	-	59.3	83.2
• Hydrochloric acid ion exchange	4.4	- 3.3		47.5
• Nitric acid ion exchange	N.A.	N.A.		N.A.
• Toth alumina	N.A.	N.A.		N.A.
Aluminum				
Basy case:				
Hall-Heroult (current practice)	48.4-97.4	-	242-487	338.4-681.8
• Hall-Heroult (new)	18.6	- 29.8 to -78.8		130.2
• Aloca chloride	N.A.	N.A.		N.A.
• Refractory hard metal cathodes	45.1-94.4	- 3.3		315.7-660.8
• Combination of clay chlorination and the aloca chloride	N.A.	N.A.		N.A.
Base case:				
Bayer and Hall-Heroult (c.p.)	63.2-112.3	-	356-601	499-842
• Clay chlorination and alcoa chloride	N.A.	N.A.		N.A.

(continued)

TABLE 15. (continued)

* Based on production in 1989 being 10.8×10^6 tons of alumina, or 7×10^6 tons of aluminum, greater than in 1974.

** Estimated 1974 emissions (based on the emission factor of 7.7 lb of particulates/ton of alumina) are $7.7 \times 7.7 \times 10^6 = 59.3 \times 10^6$ lb of particulates from alumina production; and (based on the controlled emission factor of 48.4 to 97.4 lb of particulates/ton of aluminum) are $48.4 \times 5 \times 10^6 = 242 \times 10^6$ to $97.4 \times 5 \times 10^6 = 487 \times 10^6$ lb of particulates from aluminum production.

Similarly, the controlled emission factors for the alternative processes for aluminum production are lower than those for the corresponding in the alternative processes and increased collection efficiency of hoods in the Hall-Heroult process based on prebake cells. Particulate emissions for the alumina and aluminum industry are shown in Table 15.

Clearly there is insufficient data in several of the processes from which to draw conclusions concerning the significance of particulate emissions to industry decisions. Further, some of the processes are grossly different in character and the particulates generated may also be different; unfortunately it is not currently possible to predict whether such differences (if they exist) will simplify or complicate removal.

Based on the analysis carried out on the original study (Volume VIII), the alternative alumina processes will not offer energy advantages. They are, however, based on domestic resources which might have to be called upon in the future.

CEMENT INDUSTRY

Base Case Process - Long Dry Rotary Kiln

The base case process selected for the cement industry was the long dry rotary kiln. Hydraulic cement is a powder made by burning lime, silica, alumina, iron, and magnesia together in a kiln and then pulverizing the product. The production of finished cement from raw materials involves four steps: crushing, grinding, clinkering, and finish grinding. Dry grinding is used in the dry process. This is very much like wet grinding, except that no water is added and the material is ground dry, usually at 1% moisture content or less. (A detailed description of the process is given in Volume X, page 84.)

The major source of particulate emissions in a cement plant is the kiln. Dust is generated in kiln operations by the hot combustion gases entraining feed particles. Also involved in the tumbling action within the kiln, the liberation of gases during calcination (which tends to expel particles into the gas stream), and the condensation of material that is volatilized at the firing end of the kiln. Volatilization and condensation generally produce smaller particles than the mechanical processes, thereby increasing the difficulty of removal for the air pollution cleaning system.

As clinker is discharged from the lower end of the kiln, it is passed through a clinker cooler that reduces the temperature of the clinker. The clinker cooler represents another source of airborne pollutants. The exhaust gas from the cooler may be used as combustion air in the kiln. In this case, cooler will not be a source of particulate emissions.

Emissions from the crusher area depend on the type and moisture content of the raw material and the type and characteristics of the crusher. If the material has a high moisture content, there may be little emissions, so it may not be necessary to provide dust control.

In a wet-process plant, the performance of an electrostatic precipitator is greatly enhanced by the extra water vapor in the exhaust gases from the slurry. Dry-process kilns do not have water in the feed, so it is often necessary to add water as an aid to the precipitator operation. In the past, the operation of electrostatic precipitators has not been entirely satisfactory, because of decreasing efficiency over extended periods due to the effects of the cement dust on the high-voltage components. Also, when kilns have been shut down and then restarted, it has been necessary to bypass the electrostatic precipitator for periods of up to 24 hours, because of the danger of explosion from combustible gas or coal dust.

Fiberglass bag filters have had much success in controlling kiln emissions. Bag life averages 18 months or more. Also in baghouse installations, duct designs are simple and uncomplicated, requiring little study for the flow of gases compared with the frequently complicated model studies necessary for good gas-flow patterns in the electrostatic-type dust collector.

Moisture condensation in glass-fabric filters can present problems, However, dew point temperatures are normally avoided by proper application of insulation to ducting, etc., and by proper operation to avoid condensation.

Uncontrolled emissions from the long dry kiln are 245 lb of particulate/ton of cement (AP-42). Emissions can be controlled in bag filters (collection efficiency 99.8). The lower efficiency of multicylcones (80%) and electrostatic precipitators (95%) may not be acceptable for new plants. Estimated emissions from bag filters are less than 0.5 lb/ton of cement. For the purposes of this study, it is presumed that the kiln is fired with gas or oil, but not coal. In any case, since clinkering is a direct fired process, the emissions commingle with the process particulates.

Electricity consumption in the base case process is equivalent to 1.6×10^6 Btu/ton of cement (Volume X, page 30). Estimated emissions from power boilers are 12.8 lb/ton of cement with no control, and 0.16 lb/ton of cement with control to meet the NSPS.

Process Option 1 - Suspension Preheater Process--

The suspension preheater is a modification of, or addition to, the cement rotary kiln. It is attached to the raw feed inlet end of the kiln, and totally replaces the preheating zone. The suspension preheater reheats the raw material and also accomplishes a considerable amount of raw material calcination. Typical suspension preheaters heat cold raw

feed to approximately 1,400°F (760°C) and accomplish 30 to 40% of the total calcination or thermal decomposition of the calcium carbonate, the main component of the raw feed. Consequently, with the suspension preheater, the rotary kiln receives hot and partially calcined raw material. (There are several variations on the suspension preheater and these are described in Volume X, page 19.)

One of the environmentally advantageous aspects of the suspension preheater is its ability to trap the alkalies and sulfur values within the lower and higher temperature stages of the preheater. These alkalies remain with the cement clinker. In some cases, this may not be acceptable because of the alkalies present in the cement (product quality is affected by the presence of alkalies). Therefore, a four-stage suspension preheater, operating with no bypass, would send to the dust-collecting system a relatively cool combustion gas stream containing solid particulate material which is physically and chemically similar to cement raw feed and can, usually, be recycled.

Uncontrolled emissions from this alternative design cannot be estimated, because a suspension preheater removes some of the particulate matter. If bag filters are used for particulate control, the outlet concentration will be comparable to that in the base case process. The estimated controlled emissions are then 0.35 lb/ton of cement.

The electricity consumption in this alternative process is equivalent to 1.32×10^6 Btu/ton of cement (Volume X, page 30). The estimated emissions from the power boiler are 10.6 lb/ton of cement with no control and 0.13 lb/ton of cement with control to meet the NSPS. This option conserves considerable energy and also reduces loss of material as particulates.

Process Option 2 - Flash Calciner Process--

Although the designs of flash calcining systems vary, the main feature which characterizes the flash calciner rotary kiln is the flash calcining vessel added between the rotary kiln and the suspension preheater. A detailed process description is given in Volume X, page 34.

The flash calciner arrangement (described in Volume X, page 23) requires a considerable amount of excess combustion air in burning the fuel in the rotary kiln so that enough air is present in the combustion gases leaving the kiln to permit combustion of the fuel in the flash calcining vessel. The quantity and dust loading of the combustion gas stream leaving a flash calciner should be essentially the same as for a comparable suspension preheater; however, there are no data in the available literature to clarify this. The difference would be in the gases leaving through a bypasss. If bag filters are used for particulate control, the outlet concentration may be the same as that in the base case process. Estimated controlled emissions are 0.35 lb/ton of cement.

The electricity consumption in this alternative is the same as in the suspension preheater alternative. Estimated emissions from power boilers are 10.6 lb/ton of cement with no control, and 0.13 lb/ton of cement with control to meet the NSPS.

Process Option 3 - Fluidized-Bed Cement Process--

The only difference between the fluidized-bed, cement-making process and the conventional process is the high-temperature clinkering step. All of the other steps are essentially identical. A detailed description of the process is given in Volume X, page 40. The energy consumption in the fluidized bed is about 10% higher than the long kiln (Volume X, page 46). However, there is a net electricity generation in the fluidized bed process.

The composition of the solid particulates carried from the fluidized-bed cement reactor is very different from that of rotary kiln dust. Rotary kiln dust consists of partially calcined cement raw feed and potassium and sodium sulfates in the range of 5-10% total alkalies, expressed as the stoichiometric equivalent of sodium oxide. In contrast, it is reported that the solid particulates carried by the hot combustion gases existing the fluidized-bed cement reactor consist of 97% water-soluble potassium and sodium sulfates, and only 3% cement clinker. Therefore, since the dust from the fluidized-bed process is essentially pure potessium and sodium sulfate, the quantity of dust collected per ton of cement clinker produced is very small compared with the dust collected from the conventional rotary kiln process.

Alkali compounds emitted with the effluent gases from the fluidized bed are estimated to be 50 lb/ton of clinker product (Volume X, page 43). Controlled emissions are estimated to be 0.75 lb/ton of cement, based on an estimated collection efficiency of 98.5%.

There is a net electricity generation in this alternative (Volume X, page 46). The estimated emissions at the power boiler which are offset by this generation are 1.2 lb/ton of cement with no control, and 0.015 bl/ton of cement with control to meet the NSPS.

Process Option 4 - Conversion to Coal Fuel from Oil and Natural Gas--

The process using coal as a fuel in the cement kiln is described in Volume X, page 60. Particulate emissions from the process and power boiler are not affected by switching the fuel from oil or natural gas to coal. Direct firing allows the coal ash to be incorporated in the clinker to between 50 and 100%. The remainder is removed along with the cement dust (see Volume X, page 70).

Summary

The particulate emission factors for the cement industry base case process and the process alternatives are summarized in Table 16. Uncontrolled emission factors are highest for the long dry kiln, based on gas, oil, or coal as fuel. Uncontrolled emissions from the fluidized bed are lowest.

Emissions from the cement manufacturing processes can be controlled by bag filters. Controlled emission factors are also shown in Table 16. Controlled emission factors for the alternative processes are 15 to 30% lower than for the base case process, except for the alternative in which coal is used as a fuel. Particulate emissions for the processes studied are summarized in Table 17.

As noted earlier, the properties of the dust may have a marked effect on its removability as well as upon its ecological impact. Chemical composition and size distribution (see Volume II, Table IV-13, page 76) may be expected to change over the years as other processes become important.

GLASS INDUSTRY

Base Case Process - Regenerative Furnace

The base case process selected for study was the natural gas-fired furnace with cold charge. (A detailed description of the furnace is given in Volume XI, page 17.) Operating conditions for the base case process are:

- Furnace type: Side port, regenerative
- Fuel: Natural gas
- Glass type: Soda lime
- Plant location: East North Central
- Pull Rate: 200 tons per day
- Feed Rate: 240 tons per day
- Efficiency: 90%, or 180 tons per day

A typical glass melting operation is described in detail in Volume XI, page 19. A glass melting furnace has both particulate and gaseous emissions which must be controlled.

The uncontrolled particulate emission factor for the glass furnace is 2.0 lb/ton of glass (AP-42). More than 90% of the particles are less than 0.6 microns in diameter, and about 50% are less than 0.1 micron in diameter (Volume XI, page 28), making these emissions some of the most difficult to control.

High pressure drop scrubbers (ΔP = 65 inches WG) have been reported to remove only 95% of the particles. Conventional electrostatic precipitators have collection efficiency limits similar to those of wet scrubbers.

TABLE 16. ESTIMATED PARTICULATE EMISSION FACTORS - CEMENT INDUSTRY

Process	Emission factor - no control (lb/ton of cement)			Emission factor - with control (lb/ton of cement)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case:							
Long dry rotary kiln	245	12.8	257.8	0.5	0.16	0.66	99.7
• Suspension preheater	N.A.	10.6	N.A.	0.35	0.13	0.48	-
• Flash calciner	N.A.	10.6	N.A.	0.35	0.13	0.48	-
• Fluidized bed	50	- 1.2	48.8	0.75	- 0.01	0.74	98.5
• Coal as fuel instead of gas or oil in long dry kiln	245	12.8	257.8	0.5	0.16	0.66	99.7

TABLE 17. ESTIMATED PARTICULATE EMISSIONS - CEMENT INDUSTRY

Process	Total controlled particulate emission factor (lb/ton of cement)	Change in emission factor	Particulate emissions (10^6 lb/yr) 1974**	1989-1974*
Base case:				
Long dry rotary kiln**	0.66	-	52.1	18.0
• Suspension preheater	0.48	- 0.18		13.1
• Flash calciner	0.48	- 0.18		13.1
• Fluidized bed	0.74	+ 0.08		20.2
• Coal as fuel instead of gas or oil in long dry kiln	0.66	0		18.0

* Based on production of cement in 1989 being 27.3×10^6 tons greater than in 1974.

** The particulate emissions (based on the emission factor of 0.66 lb/ton of cement in the year 1974) are $0.66 \times 79 \times 10^6 = 52.1 \times 10^6$ lb/yr.

Emissions from very few of the glass melting furnaces in the United States are currently controlled, because of the difficulty of control. The operating problems include corrosion because of chemicals containing boron, sulfur, and fluorine, as well as plugging and solids deposition. Presence of condensable particulates is also a problem in the use of precipitators and bag filters operating at high temperatures, because the particulate loading downstream of the control device is increased due to condensation. There is no typical air pollution control system readily available to serve as a basis for estimating collection efficiency. It is estimated that particulate removal efficiency of about 95% will be required to meet operating standards, so a controlled emission factor is estimated at 0.1 lb/ton of glass. In many cases, even though this standard can be met, it is difficult to meet opacity standards.

The electricity consumed in the base case process in 19 kWh/ton of glass (Volume XI, page 31). Estimated emissions from power boilers are 1.6 lb/ton of glass with no control, and 0.02 lb/ton of glass with control to meet the NSPS as shown in Table 18.

Process Option 1 - Coal Gasification--

Coal gasification processes include, in some variation, the following steps: coal handling and storage, coal preparation, gasification, oxidant feed facilities, and gas cleaning. The gas produced from coal gasification is used as a fuel source in the glass furnace. The details of the process are given in Volume XI, page 32.

When coal gasification is used to generate the gaseous fuel for the glass melting furnace, the major environmental difference is not in the glassmaking process, but rather in the fuel-generating process. Typically, the gas produced in the coal gasifier will contain particulates. Cyclones used for removal of tar from the gas will remove some of the particulates. However, the particulate collection efficiency of the cyclone is low, so the gas entering the glass furnace will not be free of particulates. There are no effluent gases (waste) in the gasification process and therefore it does not create any particulate emissions.

Particulate emissions from the glass furnace will increase over the base case in this alternative, because the fuel gas used for heating the glass contains particulates and also the exhaust gas volume is about 10% higher than that in the base case process. Uncontrolled emissions in this alternative cannot be estimated, because no data are available.

The control equipment used in this alternative is the same as in the base case process, except that the equipment used in this alternative will be physically larger because of the increase in gas volume. Controlled emissions will be slightly higher than those in the base case process.

TABLE 18. ESTIMATED PARTICULATE EMISSION FACTORS - GLASS INDUSTRY

Process	Emission factor[a] - no control (lb/ton of glass)			Emission factor[a] - with control (lb/ton of glass)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: Regenerative furnace	2.0	1.6	3.6	0.1	0.02	.12	96.7
• Coal gasification	> 2.0[b]	1.6	> 3.6	∿ 0.1[b]	0.02	∿ .12	-
• Direct coal firing	> 2.0[b]	1.6	> 3.6	> 0.1[b]	0.02	> .12	-
• Coal fired hot gas generation	N.A.[b]	1.6	N.A.	N.A.[b]	0.02	N.A.	-
• Electric melting	<< 2.0[b]	65.5	∿ 65.5	<< 2.0[b]	0.82	∿ .82	-
• Batch preheat with natural gas firing	< 2.0[b]	1.6	< 3.6	∿ 0.1[b]	.02	∿ .12	-

[a]Reported as lb particulate/ton of glass

[b]See text

N.A. - not available

The electricity consumed in this alternative is the same as in the base case process, so emissions from power boilers will be identical as indicated in Table 18.

Process Option 2 - Direct Coal-Firing Process--

In this option, pulverized coal is used directly in burners to supply the energy. (The details of the process are given in Volume XI, page 45.)

Particulate emissions from this alternative will be higher than those from the base case because coal combustion generates more particulates than gas combustion, and also the exhaust gas volume is about 15% higher in this alternative than that in the base case process. The uncontrolled emission factor cannot be estimated, because no data are available. The maximum increase in the particulate emissions will be equal to that generated from the coal combustion. Based on 12% ash in coal and the coal consumption rate of 62 ton/day (Volume XI, page 45), the maximum emissions from coal combustion are 75 lb/ton of glass.

The particulate control equipment used in this alternative is the same as in the baseline process, except that the equipment will be physically larger. Controlled emissions will be higher than those in the base case process.

The electricity consumed in this alternative is the same as in the base case process, so emissions from power boilers will be identical as shown in Table 18.

Process Option 3 - Coal-Firect Hot Gas Generation (COHOGG) Process Alternative--

This system generates a hot gas by separating char and volatiles, burning the char, and then mixing the products of combustion with the volatiles and burning them together. A pneumatic conveying system feeds powdered coal to the pyrolyzer along with limestone or a mixture of limestone and sodium chloride. The outlet temperature of the gases leaving the afterburner is 3,000°F. These hot gases are used in the glass melting furnace to heat the glass batch. The details of the process are given in Volume XI, page 48.

There is no difference bewteen the coal gasification alternative and that of heating the glass-melting furnace with a hot combustion gas, except the gas volume from the glass furnace is 25% higher with the COHOGG process because of the efficiency losses inherent in the system. The particulate emission factor will be higher for this alternative than that for the coal gasification alternative. The pollution control system will be the same as in the base case process, except that the equipment will be larger.

The electricity consumed in this alternative is about the same as in the base case process, so emissions from power boilers will be much the same as indicated in Table 18.

Process Option 4 - All-Electric Melting Alternative--

Glass can be heated and melted with electric current. Both the design and the operation of an all-electric, glass-melting furnace differ greatly from those of the typical natural gas-fired regenerative furnace. The electric furnace without regenerative checker structure is a much simpler design. The details of the electric furnace are given in Volume XI, page 53.

In this case, the only exhaust from the glass-melting furnace is from decomposition of carbonates, sulfates, nitrates, etc., in the glass batch. The exhaust is almost entirely CO_2 with some SO_x. Data on the particulate emissions from this alternative are not available; however, the magnitude of emissions can be realized by comparing emissions from the gas-fired and electric fiberglass furnaces. In the wool fiberglass industry, the emissions from the gas-fired regenerative furnace are 21.5 lb of particulates/ton of fiberglass and the emissions from the electric furnace are 0.6 lb of particulates/ton of fiberglass (AP-42). Similarly, the emissions in this alternative process will be significantly lower than the 2.0 lb/ton of glass reported for the gas-fired furnace. A pollution control system will not be required, because the emissions are very low in this alternative.

The electricity consumption in this alternative is 780 kWh/ton of glass (Volume XI, page 56). Estimated emissions from the power boiler are 65.5 lb/ton of glass with no control, and 0.82 lb/ton of glass with control to meet the NSPS as shown in Table 18.

Process Option 5 - Batch Agglomeration/Preheating Alternative--

Batch preheating is an energy-conserving technology relating to a process modification rather than a method of furnace heating. Hence, this technology is applicable to all of the previously discussed methods of glass making. The details of the process are given in Volume XI, page 58. The gas from the glass furnace is used to preheat the fuel materials. The effect of this operation on particulate emissions is not available; however, particulates generated from the preheater are usually large (> 1.0 micron) which can be controlled easily, so the controlled emissions will not be affected.

By improving the thermal efficiency of the furnace, this technology reduces the fuel requirement per ton of glass, thereby reducing the exhaust volume from the glass-melting furnace by 20%. Uncontrolled emissions from this alternative will be less than those in the base case process. The pollution control system will be the same as in the base case process, except that the equipment will be smaller.

The electricity consumed in this alternative is the same as in the base case process, so emissions from the power boilers will be identical.

Summary

The particulate emission factors for the base case and alternative processes are of the same order, except that the emissions from the electric furnace are significantly higher when the coal-fired power plant generating the electricity is included (Tables 18, 19). Table 19 shows a summary of estimated national emissions for 1974 and 1989 based on the industry growth rates shown in Table 1. Emission factors in the alternative processes can only be very roughly estimated for comparative purposes, because of the non-availability of data, clearly reflecting a need to carry out R&D studies of particle size, characteristics, ease of removal, and cost of removal.

Control of particulates continues to be a major problem for the industry but so too will be uninterrupted fuel supplies, particularly natural gas. Consequently, confirmation that one or more of the alternate processes can be employed without even more serious environmental consequences will be of great help in maintaining a viable industry.

PHOSPHORUS/PHOSPHORIC ACID INDUSTRY

Base Case Process - Electric Furnace Production of Phosphorus and Conversion of Phosphorus to Phosphoric Acid

Conversion of phosphate rock to elemental phosphorus involves calcination in a direct fired rotary kiln, screening, and reduction of phosphate rock to elemental phosphorus in an electric furnace. A detailed description of the process is given in Volume XIII, page 23.

Air pollution control is a significant problem in a phosphorus plant. The importance of handling dusty streams in the phosphorus plant is illustrated by the need to remove dust generated from processing raw materials (phosphate rock, coke, and silica) at a rate more than 10 times that of the product. These particulates are produced particularly in the high-temperature rotating kiln, but they also escape from conveyors, etc. They are usually finely divided and contain some carbon and fluorides. However, removal of particulates can be carried out in conventional air pollution control equipment such as cyclones, fabric filters, or electrostatic precipitators. Although dry particulate control systems are widely used, one air stream that requires scrubbing is that from the kiln, because it contains fluorides, such as HF or SiF_4; which can be easily removed in a wet-scrubber. Because of the conversion problem and reaction of fluorides with glass, precipitators or filter bags are generally not used for this application.

The uncontrolled particulate emissions from this process are 40 lb/ton of $Ca_3(PO_4)_2$ from calcination, and 2 lb/ton of $Ca_3(PO_4)_2$ from each

TABLE 19. ESTIMATED CONTROLLED PARTICULATE EMISSIONS - GLASS INDUSTRY

Process	Particulate emission factor for glass production (lb/ton of glass)			Change in emission factor	particulate emissions (10^6 1/byr)	
	Process	Boiler	Total		1974	1989-1974[a]
Base case: Regenerative furnace[b]	0.1	0.02	.12	-	3.5[b]	1.6
• Coal gasification	∿ 0.1	0.02	∿ .12	∿ 0		∿ 1.6
• Direct coal firing	> 0.1	0.02	> .12	N.A.		> 1.6
• Coal-fired hot gas generation	N.A.[b]	0.02	N.A.	N.A.		N.A.
• Electric melting	<< 2.0[b]	0.82	∿ .82	∿ + .70		∿ 10.7
• Batch preheat with natural gas firing	∿ 0.1[b]	.02	∿ .12	∿ 0		∿ 1.6

[a]Based on increment in production from 197401989 = 13 x 10^6 ton/yr. (see table 1)

[b]Estimated 1974 emissions, based on the total emission factor of 0.12 lb particulate/ton of glass, are 0.12 x 29 x 10^6 = 23.5 x 10^6 lb/yr.

N.A. - not available

material handling and grinding operation. The emissions are equivalent to about 87 lb/ton of P_2O_5 from calcination and 4.4 lb/ton of P_2O_5 from each materials handling and grinding operation (Midwest Research Institute, 1971); total emissions are about 96 lb/ton of product. The expected scrubber efficiency is 95% and the efficiencies of dry collectors (Midwest Research Institute, 1971) for materials handling and grinders are 90% and 97%, respectively. Therefore, the estimated total controlled emissions from the process are 4.9 lb/ton of P_2O_5. The particulates are, as noted, also contaminated in the carbon and fluorides.

Effluent gases from the electric arc furnace contain phosphorus gas, carbon monoxide, and particulates. The particulates are removed in an electrostatic precipitator before condensing the phosphorous for process reasons; therefore, these emissions are not included in the above estimates.

The electricity consumed in the production of phosphorus is 13,000 kWh/ton of phosphorus (P_4). The estimated particulate emissions from power boilers are about 476 lb/ton of P_2O_5 with no control, and about 6 lb/ton of P_2O_5 with control to meet the NSPS.

Process Option 1 - Chemical Cleanup of Wet-Process Phosphoric Acid--

There are a number of impurities in wet-process phosphoric acid which make it unsuitable for certain uses. Acid produced by the wet process is purified in this alternative to the degree necessary for production of sodium tripolyphosphate (Volume XIII, page 48). There are no air emissions from this purification process. The electricity consumption in the purification process is low, so the emissions are negligible. Therefore, the total emissions in the wet-process phosphoric acid, plus chemical cleanup, are quite similar to those present in the wet-process phosphoric acid (discussed below).

Wet-process acid is produced by treating phosphate rock with sulfuric acid. Phosphoric acid is formed, calcium sulfate is precipitated and filtered off, and the acid is concentrated. All the wet-process acid produced is used in the manufacture of fertilizers. A detailed description of the process is given in Volume XIII, page 35.

Particulate emissions from wet-process phosphoric acid manufacture consist of rock dust, fluoride gases, particulate fluoride, and phosphoric acid mist, depending on the design and condition of the plant. Fluorine exists as various compounds in the collection equipment; as fluorides, silico-fluorides, silicon tetrafluoride, and mixtures of the latter and hydrogen fluoride, the mole ratio of which changes in the vapor with the concentration of fluorosilicate in the liquid and with temperature. Because of the complex chemistry, the composition of emissions is variable.

The reactor, where phosphate rock is decomposed by sulfuric acid, is the main source of atmospheric contaminants. Acid concentration by evaporation provides another source of fluoride emissions. The filter is a third source of fluoride emissions. Emissions from filters are not large and can be controlled by the use of hoods, vents, and scrubbers. In addition to these three main sources of emissions, there are many miscellaneous minor sources. These include vents from such sources as acid splitter boxes, sumps, and phosphoric acid tanks. Collectively, these sources of fluoride emissions are significant, so they are often enclosed and vented to a suitable scrubber.

The particulate loading in the gas from the reactor is 0.5-3.5 gr/scf and that from the filter is 0.017 gr/scf. The paticulates are mostly fluoride compounds and include acid mist. Electrostatic precipitators or bag filters are not desirable as control devices because of the corrosion, plugging, and solids settling problems.

Uncontrolled particulate emissions from the wet process for production of phosphoric acid are 48 lb/ton of P_2O_5 (EPA, 1975). These emissions are controlled in scrubbers having 95% collection efficiency. Therefore, the estimated controlled emissions are 2.4 lb/ton of P_2O_5.

Electricity consumption in wet-process phosphoric acid production plus chemical cleanup, is about 266 kWh/ton of P_2O_5 (16 kWh/ton for chemical clean up). The estimated emissions at the power boiler are 22.3 lb/ton of P_2O_5 with no control, and .3 lb/ton of P_2O_5 with control to meet the NSPS.

Process Option 2 - Solvent Extraction Cleanup of Wet-Process Phosphoric Acid--

Cleanup of wet-process phosphoric acid is based on the fact that phosphoric acid can be transferred from solution in an aqueous phase to solution in an organic phase, such as normal butanol, and leave behind undesirable impurities, such as calcium chloride, in the aqueous layer. The organic phase can then be contacted in a separate unit with fresh water to yield a pure solution of phosphoric acid. A detailed process description is given in Volume XIII, page 60.

It is desirable that the phosphate rock be calcined prior to digestion. This process step is the same as that in the base case process for production of phosphorous in the electric furnace. Therefore, emissions present in the base case process (96 lb/ton of P_2O_5 with no control and 4.9 lb/ton of P_2O_5 with control) are present in the calcination step of this alternative. While the emissions from the solvent extraction cannot be quantified, they should be comparable to those from the wet process for phosphoric acid production (48 lb/ton of P_2O_5 with no control and 2.4 lb/ton of P_2O_5 with control). Therefore, the total process emissions from the alternative process are 144 lb/ton of P_2O_5 with no control, and 7.3 lb/ton of P_2O_5 with control.

The solvent-extraction process requires steam equivalent to about 10×10^6 Btu/ton of P_2O_5 and electricity equal to 300 kWh/ton of P_2O_5. Estimated particulate emissions from the power boiler are 105 lb/ton of P_2O_5 with no control, and 1.3 lb/ton of P_2O_5 with control to meet the NSPS.

Process Option 3 - Strong Acid Process--

Particulate emissions from the strong acid process were not estimated in the phosphorus industry report. However, we would expect particulate emissions from this process to be of the same order of magnitude as conventional wet-process phosphoric acid route which was discussed above under process option 1.

Summary

The estimated particulate emission factors for the phosphorus and phosphoric acid production processes are shown in Table 18. Uncontrolled emissions in the wet-process phosphoric acid plus chemical cleanup, alternative are considerably lower than in the base case process, because this process is wet and does not consume large quantities of electricity. In the solvent extraction alternative, uncontrolled process emissions are higher but the total emissions are lower because the consumption of electricity and therefore boiler emissions are low.

Dry collectors and wet scrubbers are used for particulate collection. Controlled emission factors shown in Table 18 vary from about 2 lb/ton of P_2O_5 to 11 lb/ton of P_2O_5. Emissions in the alternative processes are 20-80% lower than those in the base case process. Particulate emissions for the phosphorus and phosphoric acid industries are shown in Table 19 as they would be reflected nationally by shifts in processes over the coming years.

From both particulate emissions and energy viewpoints, either alternate process would offer great advantage, with the chemical cleanup being the more attractive. However, both processes also face other environmental problems which must still be resolved. Although the industry is not nearly so large as others, such as steel or petroleum refining, and its particulate emissions are also not of the same magnitude, certain problems, such as that of fluorides, suggest that control of the industry's particulate emissions should receive more than proportionate attention.

Based on the production of 1.4×10^6 ton to P_2O_5/yr in 1974, estimated emissions from the base case process are 15.3×10^6 lb/yr, and are expected to increase to 22.2×10^6 lb/yr in 1989 based on the total production rate of 2.03×10^6 ton of P_2O_5/yr. If the wet process phosphoric acid, plus chemical cleanup, is installed on the incremental production from 1974 to 1989, the total emissions in 1989 would be only 17.0×10^6 lb/yr, or if the solvent extraction process is installed on the incremental production from 1974 to 1989, the total emissions in 1989 would be 20.7×10^6 lb/yr. This suggests that alternative processes should be encouraged in this industry.

TABLE 20. ESTIMATED PARTICULATE EMISSION FACTORS - PHOSPHORIC ACID INDUSTRY

Process	Emission factor - no control (lb/ton of P_2O_5)			Emission factor - with control (lb/ton of P_2O_5)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case:							
Electric furnace	96	476	572.0	4.9	6	10.9	98.1
• Wet-process phosphoric acid plus chemical group	48	22.3	70.3	2.4	.3	2.7	96.1
• Solvent extraction cleanup of wet-process phosphoric acid	144	105	249.0	7.3	1.3	8.6	96.5

TABLE 21. ESTIMATED PARTICULATE EMISSIONS - PHOSPHORIC ACID INDUSTRY

Process	Total controlled particulate emission factor (lb/ton of P_2O_5)	Change in emission factor	Particulate emission (10^6 lb/yr) 1974**	1989-1974**
Base case: Electric furnace	10.9	-	15.3	6.9
• Wet-process phosphoric acid plus chemical cleanup	2.7	- 8.2		1.7
• Solvent extraction cleanup of wet-process phosphoric acid	8.6	- 2.3		5.4

* Based on production in 1989 being 0.63×10^6 ton of P_2O_5 greater than in 1974.

** Estimated 1974 particulate emissions (based on the emission factor of 10.9 lb/ton of P_2O_5) $= 10.9 \times 1.4 \times 10^6 = 15.3 \times 10^6$ lb/yr.

Other alternative processes considered, but from which emission data are not available from the industry reports, include byproduct sulfuric acid, strong phosphoric acid process, and secondary options.

COPPER INDUSTRY

Base Case Process - Conventional Copper Smelting

The conventional copper-recovery process involves smelting of sulfide concentrates in a reverberatory furnace, either directly or after roasting. The mixture of molten sulfides from the furnace is converted to blister copper in converters. (A detailed description of this process is given in Volume XIV, page 23.)

There are three sources of particulate emissions: roasters, reverberatory furnaces, and converters. The particulate loading of the waste gases depends on the characteristics of the copper concentrates and the volume of exhaust gas. Particulate emissions from the furnaces are predominantly metallic fumes of submicron size. The fumes are difficult to wet and readily agglomerate. In addition, they are cohesive and will bridge and arch in hoppers and other collection bins. The following emissions represent typical values.

The emission factor reported for roasters is 45 lb of particulate/ton of copper (AP-42). In addition to particulates, roaster gas contains SO_2 which is recovered in an acid plant. The acid plant requires particulate-free gas, so particulate removal devices with high efficiency are part of the control system. Collection efficiencies up to 99.7% for particulates are attained by careful conditioning of flue gas (Midwest Research Institute, 1971). The control equipment used is the electrostatic precipitator alone or in combination with a pre-cleaner. The estimated controlled emissions are 0.14 lb/ton of copper.

The emission factor reported for a reverberatory furnace is 20 lb/ton of copper. The furnace emits a large volume of gas (82,000 scfm from a copper smelter having an annual capacity of 100,000 ton/yr) having 1-2% SO_2. The SO_2 cannot be economically recovered from the gas (Volume XIV, page 27). Particulate control efficiency has been reported to be 99.7% (Midwest Research Institute, 1971). Electrostatic precipitators preceded by mechanical collectors are used as control equipment. The estimated controlled emissions from the reverberatory furnace are 0.06 lb/ton of copper.

The emission factor reported for a converter is 60 lb/ton of copper (Midwest Research Institute, 1971). Since the majority of the particles are large, about 75 to 85% of the solids settle in the flue system. The particulates are further removed in high-efficiency electrostatic precipitators. The SO_2 in the cleaned gas is recovered in the acid plant downstream of the precipitator. The estimated controlled emissions from the converter amount to 0.18 lb/ton of copper.

Electrostatic precipitators, preceded by mechanical collectors, are usually applied to the control of particulates from roasters, reverberatory furnaces, and converters. The equipment is usually more massive and rugged than its counterpart in other industries, such as utilities.

Total uncontrolled emissions from the above three sources in the base case process are about 125 lb/ton of copper and estimated controlled emissions are 0.38 lb/ton of copper.

The electricity consumption in the base case process ranges from 347 to 441 kWh/ton of copper (Volume XIV, page 37). Estimated emissions from steam generators are 34 lb/ton of copper with no control, and 0.42 lb/ton of copper with control to meet the NSPS.

Process Option 1 - Outokumpu Flash-Smelting Process--

The flash-smelting alternative combines the separate roasting and smelting operations of conventional copper extraction into one combined roasting/smelting operation. The major advantages of the method are a reduction in fuel used for smelting and production of a gas stream having a concentration of SO_2 which is suitable for sulfuric acid manufacture. A detailed description of the process is given in Volume XIV, page 41.

The emission sources in this process include: rotary kiln, concentrator, and converter. The particulate characteristics are expected to be the same as those for the particulates in the base case process.

A direct oil-fired rotary kiln is used to dry the charge thoroughly before it is fed to the concentrate burner. The particles leave the kiln as flue dust and are collected in an electrostatic precipitator and returned to the main concentrate flow. The uncontrolled or the controlled emission factor for this source is not reported; therefore, emissions from the rotary kiln are estimated based on the reported emission factors of kilns in other industries. Rotary kilns used in the cement- and lime-manufacturing industries generate particulate emissions in the range of 200 to 250 lb/ton of product (EPA, 1975). It is estimated that uncontrolled emissions from a rotary kiln used to dry the charge may be about 250 lb/ton of copper. If the emissions are controlled in an electrostatic precipitator with 99% collection efficiency, the uncontrolled emissions are estimated at 2.5 lb/ton of product.

The concentrator represents another source of particulate emissions, but emission data from this source are again not available so the uncontrolled emission factor cannot be estimated. The gas is cleaned in electrostatic precipitators before SO_2 removal. Assuming the concentration of particulates in the gas stream downstream of the precipitator is the same as that in the base case, the estimated controlled emissions from the concentrator would be 0.41 lb/ton of copper. The above assumption is based on the fact that gases in both processes have to be purified to meet the requirements for the acid plant.

The emissions from the converter in the flash-smelting alternative would be comparable to or less than the emissions from the converter in the base case process because the gas volume may be reduced due to the high-grade matte (Volume XIV, page 43). Emissions from the converter are estimated at 60 lb/ton of copper with no control, and 0.18 lb/ton of copper with 99.7% control.

Total controlled emissions from this alternative are about 3.1 lb/ton of copper. Uncontrolled emissions cannot be estimated, because data are not available. The control technology used in this alternative is the same as that in the base case process.

The electricity consumption in this process alternative is 366 kWh/ton of copper (Volume XIV, page 52). Estimated uncontrolled emissions from power boilers are 30.7 lb/ton of copper with no control, and 0.38 lb/ton of copper with control to meet the NSPS.

Process Option 2 - Noranda Process--

The Noranda process combines the three operations of roasting, smelting, and converting of copper concentrates in a single reactor. The heat losses suffered during the transfer of concentrate from the roaster to the reverberatory furnace are suppressed, as are those occurring during the transfer of the matte from the reverberatory furnace to the converter. A detailed description of the process is given in Volume XIV, page 55.

Data on the particulate emissions from the Noranda process are not available; however, the major emission source is the Noranda reactor. The particulate characteristics are expected to be the same as those for the particulates in the base case process. The gas flow rate from the Noranda reactor is estimated at 55,000 scfm from a plant having a capacity of 100,000 tons of copper/yr. The gas from this reactor is treated in an electrostatic precipitator for particulate removal and the clean gas is sent to an acid plant. Controlled emissions -- assuming that the concentration of particulates in the gas entering the acid plant is the same as that in the base case process -- amount to about 0.41 lb/ton of copper.

The electricity consumption in this process alternative is the same as in the Outokumpu flash-smelting alternative, so the estimated emissions from the steam generator are 30.7 lb/ton of copper with no control, and 0.38 lb/ton of copper with control to meet the NSPS.

Process Option 3 - Mitsubishi Process--

The Mitsubishi process consists of three metallurgical stages, each of which is carried out in a separate furnace. Thus, there is a smelting furnace for concentrates, a converting furnace to oxidize iron in the matte and make blister copper, and a slag-cleaning furnace. Intermediate products in the molten state move continuously among the respective furnaces, which are thus functionally connected with each other. A detailed description of the Mitsubishi process is given in Volume XIV, page 71.

All of the three furnaces represent particulate emission sources. Again, uncontrolled emissions cannot be estimated because data are not available; however, particulate characteristics are expected to be the same as those for the particles in the base case process. The estimated controlled emissions would be 0.41 lb/ton of copper, based on the assumption that the concentration of particulates in the flue gas entering the acid plant is the same as that in the base case process.

The electricity consumption in this alternative is 366 kWh/ton of copper (volume XIV, page 81). Estimated uncontrolled emissions from the steam generator are 30.7 lb/ton of copper with no control, and 0.38 lb/ton of copper with control to meet the NSPS.

Process Option 4 - The Use of Oxygen in Smelting--

Copper smelting can be conducted with pure oxygen or by using oxygen-enriched air. A detailed description is given in Volume XIV, page 82. The specific example selected for examination is Outokumpu flash smelting. The particulate emissions from this alternative cannot be estimated, because no data are available. Oxygen enrichment results in the reduction of effluent volume, but operating temperatures are generally increased. Therefore, the emissions would be lower because of the low gas volume, but the effect of temperature is not known; so the change in emissions cannot be predicted. If the gas is cleaned to the same particulate concentration as that in the base case process, the controlled emissions in this alternative will be lower than those in the base case process because the gas flow rate is lower.

Process Option 5 - Metal Recovery from Slag--

In conventional copper smelting, converter slag is recycled to the reverberatory furnace and all the slag tapped from the furnace is discarded. The copper contained in the discarded slag is lost. The amount of copper lost is significant; about 1.5 to 3.0% or more of the copper in the feed materials. Two processes for recovering metal from slag -- flotation and the electric furnace -- are described in volume XIV, page 85.

In the flocculation process, cooling, crushing, and grinding represent the particulate emission sources. In the electric furnace process, the furnace itself is the emission source, but the volume of gas is small. The emissions from these sources cannot be quantified, because no data are available.

Process Option 6 - The Arbiter Process --

The Arbiter process is a hydrometallurgical process. A process description is given in Volume XIV, page 95. Particulate emissions from this alternative cannot be quantified, because no data are available, but the process itself causes little air pollution. The process is energy-intensive and uses large quantities of electricity and steam. As reported (Volume XIV, page 104), steam consumption is 20,000 lb/ton of copper and electricity consumption is 3,0-0 kWh/ton of copper. The estimated particulate emissions from the steam generator are 410 lb/ton of copper with no control, and 5.2 lb/ton of copper with control to meet the NSPS. Thus, the Arbiter process, in addition to not having the anticipated energy benefits, also has rather significant environmental problems.

Summary

The particulate emission factors for the copper industry are summarized in Table 22. The uncontrolled emission factors in most of the pyrometallurgical processes cannot be estimated, but may be of the same order as those for the base case process, except for the Outokumpu flash-smelter alternative where a kiln is part of the process and may generate significantly more particulates.

The uncontrolled emissions from the hydrometallurgical process (Arbiter) are significantly lower than those from the pyrometallurgical processes because of the nature of the hydrometallurgical process; however, the total emissions, including those from the steam generators, are significantly higher for the hydrometallurgical process because of the consumption of large quantities of steam and electricity.

TABLE 22. ESTIMATED PARTICULATE EMISSION FACTORS - PRIMARY COPPER INDUSTRY

Process	Emission factor - no control (lb/ton of copper)			Emission factor - with control (lb/ton of copper)			Control efficiency (%)
	Process	Power boiler	Total	Process	Power boiler	Total	
Base case: Conventional smelting	125	34	159.0	0.38	0.42	0.80	99.5
• Outokumpu flash smelting	N.A.	30.7	N.A.	3.1	0.38	3.5	--
• Noranda	N.A.	30.7	N.A.	0.41	0.38	0.79	--
• Mitsubishi	N.A.	30.7	N.A.	0.41	0.38	0.79	--
• Arbiter	low	410	410.0	low	5.2	5.2	98.7

TABLE 23. ESTIMATED PARTICULATE EMISSIONS - COPPER SMELTING

Process	Total controlled particulate emission factor (lb/ton of copper)	Change in emission factor	Particulate emission (10^6 lb/yr) 1974**	1989-1974*
Base case: Conventional smelting	0.80	-	1.3	.9
• Outokumpu flash smelting	3.5	+ 2.7		3.8
• Nornada	0.79	- .01		.9
• Mitsubishi	0.79	- .01		.9
• Arbiter	5.2	+ 4.4		5.7

* Based on production in 1989 being 1.1 million tons greater than in 1974.

** Estimated 1974 emissions (based on the emission factor of 0.8 lb of particulate/ton of anode copper)are $0.8 \times 1.6 \times 10^6$ lb/yr.

Particulate emissions in the copper industry are well controlled for the simple reason that the gas contains sulfur dioxide, and the sulfur dioxide recovery plants require particulate-free gas. The controlled emissions from most of the pyrometallurgical processes are reduced to about 0.4 lb/ton of copper.

The controlled emission factors for the base case process and alternative processes are comparable, except for the Outokumpu flash-smelter and Arbiter process alternatives. In the Outokumpu flash-smelter alternative, emissions are higher, because a kiln which produces large emissions is part of the process; in the Arbiter process, alternative emissions are also higher because of the large consumption of electricity and steam.

Emissions from the copper industry are summarized in Table 23. As seen here, the controlled emissions from the alternative processes are comparable to those in the base case process or higher. The total particulate emissions are estimated at 1.3×10^6 lb/yr, based on the production rate of 1.6×10^6 tons of copper/yr in 1974; and are expected to increase to about 2.2×10^6 lb/yr in 1989, based on the estimated production of 2.7×10^6 tons/yr. However, if the Outokumpu flash smelting process, or the Arbiter process, is installed over the incremental capacity from 1974 to 1989, the total particulate emissions in 1989 will increase to 5.1×10^6 lb/yr or 7.0×10^6 lb/yr, respectively, significantly higher than those with the base case process.

AMMONIA INDUSTRY

In the remaining industry sectors, particulate emissions from the processes were not considered to be of major importance in the original 13 industry study. However, in many cases, there may be significant differences in electric power or steam requirements which could affect emissions at the power boiler. These remaining industry sectors are discussed in the following text.

The base case technology is the production of ammonia based on steam reforming and using natural gas as the feedstock. In the alternative processes, ammonia is produced via coal and heavy oil feedstocks. Estimated particulate emissions are summarized in Table 24 with details presented in the following discussion.

Base Case Process - Ammonia Production Based on Gas Feedstock

The four major operations in the manufacture of ammonia include: gas preparation, hydrogen production, gas purification, and ammonia

TABLE 24. ESTIMATED CONTROLLED PARTICULATE EMISSIONS - AMMONIA INDUSTRY

Process	Particulate emission factor for ammonia production (lb/ton of ammonia)			Change in emission factor	Particulate emission (10^6 lb/yr)	
	Process	Power boiler	Total		1974**	1989-1974*
Base case:						
Natural gas	0.21	0.05	0.26	-	2.4	3.3
• Coal gasification	0.52†	0.17	0.69†	+ 0.43†		8.8†
• Heavy fuel oil	0.08	0.11	0.19	- 0.07		2.4

* Based on production in 1989 being 12.8×10^6 tons greater than in 1974.

** Estimated 1974 emissions, based on the total emission factor of 0.26 lb of particulate/ton of ammonia, are $0.26 \times 9.2 \times 10^6 = 2.4 \times 10^6$ lb/year.

† Coal dust emissions from receiving, handling, and grinding operations are not included in this emission factor.

synthesis. Gas is typically prepared by steam reforming of desulfurized natural gas to produce carbon monoxide and water. In the second step, the project gases are normally catalytically shifted to carbon dioxide and hydrogen. The carbon oxides are reacted with water to form more hydrogen. Ammonia is then synthesized by the reaction between hydrogen and nitrogen (produced from atmospheric air) at elevated temperatures and pressures in the presence of a catalyst. A detailed description of the base case technology is presented in Volume VII, page 25.

Process energy requirements include natural gas (12.6×10^6 Btu/ton) which is used to fire the steam reformer. Steam is generated by heat recovered from the flue gas leaving the primary reformer and from the process gases leaving the secondary reformer. Additional steam is generated from auxiliary gas-fired boilers only during startup. Power requirements are estimated at 45.5 kWh/ton of ammonia.

Particulate emissions from the natural gas-fired reformer -- based on the emissions factor of 0.017 lb/10^6 Btu (EPA, 1975) -- are estimated to be 0.21 lb/ton of ammonia.

Particulate emissions from the power boiler are estimated to be 3.82 lb/ton if the emissions are uncontrolled, and 0.05 lb/ton of ammonia is emissions are controlled to meet the NSPS.

Process Option 1 - Ammonia Production Based on Coal Gasification

Synthesis gas for ammonia production is obtained from the coal feedstock by freeing the hydrogen that is present in the coal and by reacting the carbon in the coal with steam to produce additional hydrogen and carbon monoxide. As in the base case process, the synthesis gas is shifted to a hydrogen and carbon dioxide product, the gases are purified, and ammonia is synthesized from nitrogen to the hydrogen product. The details of this process option are described in Volume VII, page 37.

An auxiliary coal-fired boiler is required for this process alternative. Coal requirements are estimated at 5.22×10^6 Btu/ton of ammonia. In addition, electrical power requirements nave been estimated to be 1.70×10^6 Btu/ton.

Particulate emissions from the process heat requirements are estimated at 0.52 lb/ ton of ammonia, if emissions are controlled to meet the NSPS, and 41.76 lb/ton of ammonia, if emissions are uncontrolled. Particulate emissions from the coal unloading, handling, and grinding operations have not been estimated.

Particulate emissions from the power requirements are estimated at 13.61 lb/ton if emissions are uncontrolled, and 0.17 lb/ton if emissions are controlled to meet the NSPS.

Process Option 2 - Production of Ammonia from Heavy Fuel Oil--

The production of ammonia from heavy fuel oil involves producing synthesis gas from fuel oil by the partial oxidation and steam reforming of the hydrocarbons. The carbon monoxide and steam in the product gases are subsequently reacted catalytically to produce additional hydrogen. The acid gases, carbon oxides, and other impurities are removed from the hydrogen stream. Ammonia is finally synthesized from the hydrogen and nitrogen. An air separation plant supplies nitrogen for the synthesis and oxygen for the partial oxidation of the fuel oil. This process option is described further in Volume VII, page 67.

Process fuel requirements were estimated to include fuel oil and naphtha at approximately 7.26×10^6 Btu/ton of ammonia. Power requirements are estimated at 103 kWh/ton.

Controlled particulate emissions from process fuel, based on an emissions factor of 0.011 lb/10^6 Btu (Volume VII, page 71, 76) are estimated to be 0.08 lb/ton.

Particulate emissions from the power boiler are estimated to be 8.65 lb/ton if emissions are uncontrolled, and 0.11 lb/ton of ammonia if emissions are controlled to meet the NSPS.

CHLOR-ALKALI INDUSTRY

Chlorine and Cuastic Production

Base Case Process - Graphite Anode Diaphragm Cell--

The graphite anode diaphragm cell was selected as a basis for judging the energy and environmental effects resulting from the process changes studied, i.e., conversion to both modified annodes and diaphragms, both changes being aimed at energy conservation.

Chlorine and caustic soda are produced by the electrolysis of brine. In the Diaphragm cell, chlorine is formed at the graphite anode, while sodium ions migrate through the cell diaphragm to the cathode where a dilute solution of NaOH is produced. A more detailed description of this process is presented in Volume XII, page 21-25.

The electrolysis of brine is an energy-intensive process requiring about 3,274 kWh/ton of chlorine. In addition, the plant requires 7,368 lb of low-pressure steam/ton of chlorine for caustic evaporation and brine heating.

Particulate emissions from power generation are estimated at 3.44 lb/ton of chlorine if the NSPS for coal-fired units is met. Without particulate removal, emissions are estimated at 275 lb/ton of chlorine. It was assumed (Volume XII, page 26) that the steam would be generated with

byproduct hydrogen supplemented with natural gas. Uncontrolled particulate emissions from steam generation, based on the emissions factor 0.017 $lb/10^6$ Btu (AP-42), are estimated to be 0.16 lb/ton of chlorine.

Process Option 1 - Dimensionally Stable Anode--

The dimensionally stable anode (DSA), constructed of titanium and coated with precious metal/rare earth oxides, offers power savings of up to 20% over the graphite anode. Moreover, the anode area and anode-cathode spacing of the DSA remain constant throughout use, thereby preventing increased voltage requirements over time. Additional characteristics of the DSA are presented in Volume XII, page 44-47.

The DSA diaphragm cell process requires 3,151 kWh and 6,402 lb of steam/ton of chlorine. Steam is generated by the byproduct hydrogen and natural gas. Uncontrolled particulate emissions from steam generation are estimated to be 0.14 lb/ton of chlorine. Particulate emissions from power generation are estimated at 3.31 lb/ton of chlorine, if the NSPS for coal-fired units is met, and 265 lb/ton of chlorine if the emissions are uncontrolled.

Process Option 2 - Expandable DSA--

Cell power consumption can be reduced by decreasing the gap between the anode and the cathode. With the rigid DSA, a "working" space must be allowed in which to assemble the cell. The expanded DSA is constructed so that the electrodes can be moved inward after the cell is assembled. This reduced spacing results in a reduction of about 325 kWh/ton of chlorine compared to the rigid DSA configuration. If emissions are controlled to meet the NSPS, then this power savings reduces particulate emissions from the power boiler by about 0.35 lb/ton of chlorine from the particulate emissions estimated for the rigid DSA cells. If emissions are uncontrolled, then this power savings reduces particulate emissions by 27.3 lb/ton of chlorine.

Process Option 3 - Polymer-Modified Asbestos--

By replacing the conventional asbestos diaphragm by one which is polymer-treated and baked into place on the cathode, power consumption can be reduced because diaphragm swelling does not occur. Electrical consumption may be reduced by as much as 280 kWh/ton if an extra wide anode is used. Thus, particulate emissions controlled to meet the NSPS are estimated to be 0.29 lb/ton of chlorine less than the emissions estimated for the rigid DSA cells with standard diaphragms. Without particulate removal, particulate emissions would be about 23.5 lb/ton of chlorine less.

Process Option 4 - Polymer Membranes--

Microporous teflon-type polymer membranes which would replace the asbestos diaphragm entirely are being developed. These would give an energy performance equivalent to the polymer-modified asbestos with the "extra-wide" anode. Hence, the controlled and uncontrolled emissions would be identical to those of process option 3.

Process Option 5 - Ion Exchange Membranes--

These membranes would separate the anode and cathode compartments of the cell and would allow the diffusion of sodium ions to the cathode but would not allow the diffusion of hydroxyl ions to the anode. Thus, the ion exchange cell would be capable of producing a 25 to 40% caustic solution, whereas the standard cell produces a 10% caustic solution.

Energy use for a DSA with an ion exchange cell producing 40% NaOH is 2,980 kWh and 1,466 lb of steam/ton of chlorine. Significantly less steam is required since a rather concentrated NaOH solution is produced directly from the cell. Controlled particulate emissions from steam generation by natural gas and byproduct hydrogen are estimated at 0.03 lb/ton of chlorine. Particulate emissions from power generation is estimated to be 3.13 lb/ton of chlorine if the NSPS for coal-fired boilers is met. Without particulate control, emissions would be 250 lb/ton of chlorine.

Process Option 6 - Mercury Cells--

Chlorine and caustic may also be produced in a mercury cell in which brine flows through a slightly sloped trough. Chlorine is produced at the dimensionally stable anodes, located at the top of the trough. A dilute sodium amalgam is produced at the cathode (a thin layer of mercury which flows along the bottom of the trough), a 50% caustic solution is produced from the amalgam, with the mercury recycled to the cell. Energy requirements for the mercury cell include 3,712 kWh of power and 550 lb of steam/ton of chlorine.

Uncontrolled particulate emissions from steam generation by natural gas and byproduct hydrogen are estimated to be 0.02 lb/ton of chlorine. Particulate emissions produced by power generation are estimated at 3.89 lb/ton of chlorine if the NSPS for coal-fired boilers is met. Without particulate control, emissions would be about 312 lb/ton of chlorine.

Summary

The emissions factor and total emissions for the base case and alternative processes are presented in Table 25. The modified anodes and modified diaphragm options offer a 4 to 14% annual reduction in particulate emissions from the base case process.

TABLE 25. ESTIMATED PARTICULATE EMISSIONS - CHLOR-ALKALI INDUSTRY

Process	Particulate emission factor (lb/ton of chlorine) Process	Power boiler†	Total	Change in emission factor	Particulate emission (10^6 lb/yr) 1974**	1989-1974*
Base case: Graphite-anode diaphragm cell**	0.16	3.44	3.60	-	39.6	42.8
• Dimensionally stable anodes	0.14	3.31	3.45	- 0.15		41.1
• Expandable DSA	0.14	2.97	3.11	- 0.49		37.0
• Polymer-modified asbestos	0.14	3.02	3.16	- 0.44		37.6
• Polymer membrane	0.14	3.02	3.16	- 0.44		37.6
• Ion exchange membrane	0.03	3.13	3.16	- 0.44		37.6
• Mercury cell	0.02	3.89	3.91	+ 0.31		46.5

* Based on production in 1989 being 11.9×10^6 tons greater than in 1974.

** Estimated 1974 emissions, based on the total emission factor of 3.60 lb of particulate/ton of chlorine, are $3.6 \times 11.0 \times 10^6 = 39.6 \times 10^6$ lb.

† Emissions controlled to meet the NSPS for coal-fired boilers.

The mercury cell, however, is estimated to result in a 9% annual increase in particulate emissions compared to the base case, because of the relatively larger power requirements.

FERTILIZER INDUSTRY

Nitric Acid Production

The manufacture of nitric acid, described in Volume XV, page 25-28, generates significant emissions of nitrogen oxide. Adoption of air pollution control is a recent practice in the industry. The process change considered in the nitric acid production is the application of alternative NO_x abatement systems. These processes are described in Volume XV, page 33-42.

Base Case Process - Nitric Acid Production without NO_x Emission Control--

Nitric acid is produced by the oxidation of ammonia, usually under high pressure and temperature, over a platinum catalyst. Waste heat recovered from the product gases is used to generate steam. The cooled gases are subsequently sent to an absorption tower to form the acid product.

Process heating requirements are satisfied by natural gas. Steam generated by the waste heat is included as an energy credit. An analogous credit for particulate emissions was assumed since the steam generated by the waste heat would otherwise be generated by low-sulfur residual fuel oil. The particulate emissions credit, based on the emission factor of 3 lb/1,000 gal of oil burned, is estimated to be 0.01 lb/ton of acid.

Process Option 1 - Catalytic Reduction--

In the catalytic reduction process, tail gas from the absorber passes through a combustor where the nitrogen oxides are reduced to N_2 and O_2. Natural gas is used as a fuel in the combustor. Steam is generated by waste heat recovered from the product gases.

Energy requirements for the process include natural gas and electricity. Although catalytic reduction is an energy-intensive process, there is a particulate emissions credit because steam, which would otherwise be generated by oil, is generated with waste heat from the process. The net particulate emissions credit is estimated to be 0.01 lb of particulate/ton of nitric acid.

Process Option 2 - Molecular Sieve Method--

This method is based on the principles of absorption, oxidation, and regeneration of the molecular sieve. An oil-fired heater is used to provide heat for regeneration of the sieve. The process has high efficiency for removal of NO_x gases. A detailed description of the method is given in Volume XV, page 36.

Energy requirements include fuel oil, steam, and electricity. High power requirements (26 kWh/ton of acid) result from the added compression requirements and the need to regenerate the sieve. Particulate emissions from power boilers without control are estimated to be 2.17 lb/ton of acid, and 0.03 lb/ton of acid from power boilers with particulate control required to meet the NSPS. Controlled particulate emissions from the low-sulfur residual fuel oil used in the sieve regeneration and steam production are estimated at 0.4 lb/ton of acid.

Process Option 3 - Grand Paroisse or Extended Water Absorption--

In this process, tail gas form the existing absorption tower is delivered to a second absorption tower for "extended absorption nitrogen oxides by water."

The energy requirements for this process are small -- only 7.2 Kwh are used per ton of nitric acid product. Power plant emissions are estimated at 0.60 lb/ton of acid if the NSPS for coal-fired units is met, and 0.01 lb/ton of acid for plants without particulate control.

CDL/Vitak Process--

In the CDL/Vitak process, the tail gas is scrubbed with nitric acid under conditions which reduce the nitrogen oxides to the desired level. Energy requirements for this process include steam and electricity. The total steam requirements will result in particulate emissions of 1.14 lb/ton of acid if low-sulfur residual fuel oil is burned. Electrical requirements (22 kWh/ton of acid) will result in particulate emissions of 0.02 lb/ton of acid if the flue gas is cleaned to meet the NSPS for coal-fired boilers and 1.81 lb/ton if emissions are uncontrolled.

Masar Process--

In the Masar process, the tail gas is chilled and then scrubbed with an urea-containing solution. As nitric acid is produced, the urea hydrolyzes and forms ammonium nitrate. Steam (consumed at 105,000 lb/ton of acid) and electricity (consumed at 1.5 kWh/ton of acid) are required for this process. Steam generation by low-sulfur residual fuel oil will result in 2.10 lb of particulate/ton of acid. Electricity generation contributes 0.13 lb/ton of acid if emissions are uncontrolled, and a negligible amount of particulate if the emissions are controlled to meet the NSPS.

Conversion to Fuel Oil in Mixed Fertilizer Plants Equipped with Bag Filters

Base Case Process--

The base case operation is an ammoniation granulation plant which uses a natural gas-fired dryer and is equipped with a bag house filter to control fertilizer dust produced during drying. Only 20% of the

estimated 200 plants are equipped with bag houses and would therefore be affected by this process change. Uncontrolled emissions from a granulation plant are estimated at 2.91 lb/ton of fertilizer; uncontrolled emissions from the dryer and cooler are estimated at 0.46 lb/ton of fertilizer (Volume XV, page 49). Bag houses operating at 99.8% removal efficiency would reduce the emmisions from the dryer to less than 0.01 lb/ton of fertilizer. Power requirements for the bag house are estimated to be 1.7 kWh/ton. Particulate emissions are estimated to be 0.15 lb/ton from uncontrolled sources and are negligible from power boilers which meet the NSPS.

Installation of Scrubber on Bag House-Equipped Plants When Converting from Natural Gas to Fuel Oil--

When fertilizer dryers were converted from natural gas to oil, operational problems sometimes resulted when the bag house filters became plugged with ash from the oil. If these problems cannot be resolved by the modification of the combustion process, then wet scrubbers will be required for particulate control.

Incremental particulate emissions resulting from conversion to low-sulfur residual fuel oil may be considered negligible, since the fly ash would be removed in the scrubber. The lower removal efficiency of the scrubber as compared to the bag house is not sufficiently different to have an impact on the emission factor.

Power requirements for the scrubber operation are estimated to be three times greater than those for bag house operation. Particulate emissions from the power boiler are estimated to be 0.01 lb/ton of fertilizer if emissions are controlled to meet the NSPS, and 0.45 lb/ton of fertilizer if emissions are uncontrolled.

Continued Operation of the Bag House Filter after Conversion from National Gas to Fuel Oil--

If filter clogging problems can be alleviated by proper design and operation of the oil-fired dryer, the bag houses will not have to be replaced by scrubbers. Incremental particulate emissions resulting from the fuel conversion would be negligible since the fly ash would be removed in the bag house. Power requirements and emission factors for the bag house would be about the same as the base case process.

Summary

The emission factors and total emissions for the base case and alternative processes for NO_x abatement and fuel conversion in fertilizer drying are presented in Table 26. For NO_x abatement in nitric acid production, only the catalytic reduction process option offers a reduction of particulate emissions from the base case process. This is primarily a result of the large power requirements for the NO_x control systems.

TABLE 26. ESTIMATED CONTROLLED PARTICULATE EMISSIONS - FERTILIZER INDUSTRY

Process	Particulate emission factor (lb/ton of nitric acid) Process	Power boiler	Total	Change in emission factor	Particulate emission (10^6 lb/yr) 1974**	1989-1974*
Nitric acid production - control of NO_x emissions by various technologies.						
Base case: No NO_x control**	- 0.01	0.0	- 0.01	--	- 0.08	- 0.7
• Catalytic reduction	- 0.02	0.01	- 0.01	0.0		- 0.7
• Molecular sieve	0.4	0.03	0.43	.44		2.9
• Grand Paroisse	0.0	0.01	0.01	0.02		0.07
• CDL/Bitak	1.14	0.02	1.16	1.17		7.7
• Masar	2.10	< 0.0	2.10	2.11		13.9
Converting fertilizer dryers (with bag houses) from natural gas to oil.						
Base case: Natural gas	< 0.01	nil	< 0.01	--	0.11†	< 0.08††
• Better equipment technique†	< 0.01	0.0	< 0.01	0.0		< 0.08††
• Installing scrubbers	< 0.01	0.01	< 0.02	0.01		< 0.16††

* Based on nitric acid production in 1989 being 6.6×10^6 tons greater than in 1974.

** Estimated 1974 emissions based on total emission factor (credit) of -0.01 lb/ton of acid are $-0.01 \times 8.2 \times 10^6 = 0.08 \times 10^6$ ton/yr (particulate emissions credit since energy is recovered in this process).

(continued)

TABLE 26. (continued)

†Estimated 1974 emissions based on total emissions factor of 0.01 lb/ton of fertilizer are $0.01 \times 10.0 \times 10^7 = 0.10$ ton/yr.

††Calculated using a 4% growth rate for 15 years based on 10×10^6 tons/yr in 1974 and rising to 18×10^6 tons in 1989; this potential growth of 8×10^6 tons is multiplied by the emission factor.

Fuel conversion for fertilizer dryers equipped with bag house filters has a small impact on the total amount of particulate emissions on an industry-wide basis since only 20% of the fertilizer plants are equipped with these air filters.

TEXTILES INDUSTRY

Two textile mills -- an integrated knitting mill and an integrated weaving mill -- were examined. The mill operation includes the knitting of greige yarn or the weaving of greige fabric and subsequently dyeing and finishing the fabric.

Knit Fabrics Production

Base Case Process--

In the knitting mills, yarn is knitted into fabric in the greige mill. The greige fabric is next scoured to remove knitting oil, and then dyed, washed, and spun-dry to remove as much water as possible before hot-air drying. A finish (softener/lubricant) is then applied to the fabric, which is dried and heat-set. Details of the knitting mill operation are presented in Volume IX, page 33.

Natural gas is used for the hot-air drying and heat-set operations. Particulate emissions include merely a small amount of lint. The quantity of this lint is not estimated in Volume IX. It is unlikely that the natural gas will be supplemented as it is required by all of the equipment presently available for fabric drying and heat-setting operations.

Steam is used for the heat input to the scouring, dyeing, and washing operations. In the base case process, it was assumed that the steam would be generated with low-sulfur residual fuel oil. Estimated emissions -- based on the emission factor of 3 lb/1,000 gal of oil burned in the boiler -- are 0.16 lb/ton of fabric. Because of the relatively small energy requirements of textile mills, it seems unlikely that coal will be used as a fuel for steam production (Volume IX, page 41). Electricity is required to provide mechanical energy to transfer fabric from the beginning to the end of the process line and for knitting the yarn into the fabric. Electrical requirements of 360 kWh/ton of fabric will result in particulate emissions of about 0.38 lb of particulate/ton of fabric if the NSPS is met. Without particulate control, emissions will be 30.2 lb/ton of fabric.

Advanced Aqueous Processing--

In advanced aequeous processing, the sequence of operation is similar to that of the base case, except that the hot air drier is replaced by an air/vacuum extractor, thereby reducing natural gas requirements and increasing electrical requirements. Secondly, the scouring, dyeing, and washing operations are modernized with more

efficient equipment, thereby reducing steam requirements. Advanced aqueous processing is described in detail in Volume IX, page 535-537.

Natural gas is used for the heat-setting operation; hence, there are no fuel-related particulate emissions. However, some lint is emitted, although this amount was not estimated in the Textile Industry Report (Volume XI).

Steam requirements of 3,800 lb/ton of fabric will result in 0.08 lb of particulate/ton of fabric if the steam is generated by fuel oil so that flue gas desulfurization is not required. Electrical requirements of 500 kWh/ton of fabric will result in 0.53 lb of particulate/ton of fabric if the NSPS is met. Without particulate removal, emissions would be 42.0 lb of particulate/ton of fabric.

Solvent Case--

Solvent systems are assumed for the scouring, dyeing, and finishing operations. The fabric is steam-stripped to remove residual solvent. Clean solvent is recovered by distillation with steam. Details of this solvent system are provided in Volume IX, page 37-41.

Natural gas is used for the heat-setting operation; hence there are no fuel-related particulate emissions. However, some lint is emitted, although this amount was not estimated in the Textile Industry Report (Volume IX). Steam requirements of 2,200 lb/ton of fabric will result in 0.04 lb of particulate/ton of fabric. Electricity requirements of 240 kWh/ton of fabric will result in 0.25 lb of particulate/ton of fabric if the NSPS is met. Without particulate control, emissions would be about 20.2 lb of particulate/ton of fabric.

Woven Fabrics Production

Base Case Process--

The operations of woven fabric preparation, dyeing, and finishing involve a much longer processing sequence than knit fabrics. These steps are described in Volume IX, page 44. Natural gas is used in the drying, setting, and curing operations; hence, there are not fuel-derived particulate emissions in these steps. However, some lint may be emitted, although the quantity was not reported in Volume IX.

Steam (15 lb/ton of fabric) is used for process water heating in the dyeing, washing, and finishing steps. Steam generation will result in 0.6 lb of particulate/ton of fabric if low-sulfur residual oil is burned. Electrical energy requirements are estimated at 580 kWh/ton of product. This will result in particulate emissions of 0.61 lb/ton of fabric if the NSPS is met. Otherwise, uncontrolled emissions are estimated at 48.7 lb/ton of fabric.

Advanced Process--

The advanced processing includes a polyvinyl alcohol (PVA) recovery loop in which concentrated PVA solution is recycled back to sizing and the hot water back to the desizing operation. Details of the advanced case sequence are presented in Volume IX, page 49.

Natural gas is used in the drying, setting, and curing operations; hence, there are no fuel-derived particulate emissions in these steps. However, some lint may be emitted, although the quantity was not reported in Volume IX.

Steam requirements have been reduced to 6.4 lb/ton of fabric by reduction in overall process water use and recycling of wash waters. This steam generation will produce 0.25 lb of particulate/ton of fabric if these emissions are not controlled. Electrical requirements have been reduced to 300 kWh/lb of steam. This will result in particulate emissions of 0.32 lb/ton of fabric if the NSPS is met. Without control, emissions are estimated at 25.2 lb/ton of fabric.

Summary

The emissions factor and total emissions for the base case process and alternative processes are summarized in Table 27.

The particulate emissions from the advanced process for the knitted fabric are slightly higher than those from the base case process due to increased power requirements. Particulate emissions from the remaining alternatives are 50% - 53% lower than those of the corresponding base case processes.

TABLE 27. ESTIMATED PARTICULATE EMISSIONS - TEXTILE INDUSTRY

Process	Particulate emission factor (lb/ton fabric)				Particulate emission (10^6 lb/yr)	
	Process	Power boiler	Total	Change in emission factor	1974**	1989-1974*
Knit fabric						
Base case**	0.16	0.38	0.54	--	0.17	0.06
• Advanced case	0.08	0.53	0.61	+ 0.07		0.07
• Solvent case	0.04	0.25	0.29	- 0.25		0.03
Woven fabric						
Base case†	0.60	0.61	1.21	--	2.5	0.98
• Advanced case	0.25	0.32	0.57	0.64		0.46

* Based on production in 1989 being 0.12×10^6 tons (knit fabric) and 0.81×10^6 tons (woven fabric).

** Estimated 1974 emissions from knit fabric production based on the total emission factor of 0.54 lb of particulate/ton of fabric are $.54 \times 0.32 \times 10^6 = 0.17 \times 10^6$ lb.

† Estimated 1974 emissions from woven fabric production based on total emission factor of 1.21 lb of particulate/ton of fabric are $1.21 \times 2.1 \times 10^6 = 2.5 \times 10^6$ ton/yr.

REFERENCES

Edlund, C., A.H. Lambe and J. Jeffrey, Effects of Water Quality on Coke Quench Tower Particulate Emission, presented at the 70th Annual APCA Meeting, Toronto, June 1977.

U.S. Environmental Protection Agency, AP-42, Compilation of Air Pollution Emission Factors, Second Edition, March 1975.

Arthur D. Little, Inc., Steel and the Environment, report to the American Iron and Steel Institute, May 1975.

Midwest Research Institute, Particulate Pollutant System Study, Handbook of Emission Properties, Vol. III, U.S. Environmental Protection Agency, Contract No. CPA 22-69-104, May 1971.

United States
Environmental Protection
Agency

Environmental Research Information
Center
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA-335

Official Business
Penalty for Private Use
$300

Special Fourth-Class Rate
Book

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐, detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA-600/7-79-145

B57 9-